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Space Division
North American Rockwell

SATURN SUSTAINING ENGINEERING REPORT

SD72-SA-0032

SPACE TUG POINT DESIGN STUDY FINAL REPORT
VOLUME IV
PROGRAM REQUIREMENTS

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Prepared for

George C. Marshall Space Flight Center

Approved by

R. Schwartz

R. Schwartz

Chief Program Engineer

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FOREWORD

The final report on the Tug Point Design Study was prepared by the North American Rockwell Corporation through its Space Division for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with SA 2190 and Contract No. NAS 7-200.

The study effort described herein was conducted under the direction of NASA MSFC Study Leader, Mr. C. Gregg. The report was prepared by NR-SD, Seal Beach, California under the direction of Mr. T. M. Littman, Study Manager. The study results were developed during the period from 4 November 1971 through 11 February 1972 and the final report was submitted in February of 1972.

Valuable guidance and assistance was provided throughout the study by the following NASA/MSFC personnel:

C. Gregg - Study Leader
S. Denton - Structures
A. Willis - Avionics
J. Sanders - Propulsion
R. Nixon - Thermal Protection
A. Young - Flight Performance
R. L. Klan - Cost

The complete set of volumes comprising the report includes:

I Summary
II Operations, Performance, and Requirements
III Design Definition

Part 1 - Propulsion and Mechanical Subsystems, Avionic Subsystems, Thermal Control, and Electrical Power Subsystem

Part 2 - Insulation Subsystems, Meteoroid Protection, Structures, Mass Properties, Ground Support Equipment, Reliability, and Safety

IV Program Requirements
V Cost Analysis

This volume contains the program plans and planning data generated in support of the Tug development program. The preliminary plans and supporting planning data concentrates in the definition of the requirements for maintenance and refurbishment, technology development, production, test, facilities, quality control and scheduling as they relate to the Tug.

ABSTRACT

The primary objective of the Tug Point Design Study was to verify through detail design and analysis the performance capability of a baseline design to deliver and retrieve payloads between 100 nautical miles/28.5 degrees inclination and geosynchronous. The Tug as groundruled for the study, is ground-based, reusable for 20 mission cycles, and is shuttled to and from low earth orbit by an Earth Orbital Shuttle (EOS) with a 65,000 pound payload capability. A 1976 state-of-the-art also was groundruled for the investigations.

The results of the effort show that the baseline concept can be designed to meet the target performance goals. Round trip payload capability to geosynchronous orbit is 3720 pounds; 720 pound margin over the established goal.

The design analysis performed to ascertain the Tug propellant mass fraction encompassed definition of the vehicle primary structure, thermal control, meteoroid protection, propulsion and mechanical subsystems, and avionics including power generation and distribution.

Graphite-epoxy composite material was determined to be feasible for Tug use and resulted in considerable weight savings. The concept of employing the primary load-carrying outer shell as a multi-function element integrating the meteoroid shield and insulation purge bag requirements is also feasible and enhances design simplicity. In addition, the use of a dual-mode pressure schedule during boost to orbit when applied loads are highest resulted in minimum tank weight. This, combined with an integrated gaseous O_2/H_2 auxiliary propulsion for stability and control, main tanks prepressurization, and fuel cell usage yield a minimum weight and operationally simple system.

Reliability and Safety analyses verified that no single failure of a component would result in a critical or unsafe condition. This was accomplished employing redundancy as required, notably in propulsion subsystems valving and attitude control components.

Program requirements were developed to verify the feasibility, producibility and operational capability of the point design. The results indicate that an "on-condition" maintenance approach similar to that used by commercial airlines and military operations would effectively serve Tug requirements.

Technology development study effort was concentrated on identifying the technologies needed for the baseline design. The more critical technologies requiring development include high performance engines, high performance insulation, large composite structures, and avionics.

A preliminary program development schedule was structured summarizing the integrated activities necessary to support the Tug through design development, production, and ground and flight testing.

The cost analysis performed covered the five major cost categories of DDT&E, first unit production, SR&T, average flight maintenance and refurbishment, and flight test vehicle refurbishment.

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1.0 INTRODUCTION

The Space Tug is a high performance propulsion stage designed to operate as an orbital maneuvering stage launched by the two-stage Space Shuttle. Because of the nature of the Tug mission, performance capability is very sensitive to Tug mass fraction. This study was conducted to answer the questions "What Tug mass fractions are really achievable by 1980?", and "What level of technology effort is required in order to build a Tug having the high performance defined in NASA/MSFC's Study Plan (Reference 1)?". Both questions are discussed below.

1.1 BACKGROUND

Several pre-Phase A Tug/OOS (Orbit-to-Orbit Shuttle) studies have been conducted for NASA and USAF agencies with a wide variation in the mass fractions quoted. NR performed a reusable Space Tug study for NASA-MSC in 1970-71 (Reference 2) and both NR and MDAC evaluated OOS feasibility for SAMSO/Aerospace Corporation in 1971 (References 3, 4). Additionally, two European teams conducted Tug system studies for the European Space Agency (ELDO) during 1970-71 (References 5, 6). In-house investigations also have been accomplished by MSFC and Aerospace Corporation. These studies considered a wide variety of design concepts and autonomy limits, ground and space-based operational requirements, degree of reusability, unmanned and manned payload implications, single and multistages, and different technology bases.

Projected NASA and DOD missions for the 1980's and beyond demand a Tug designed for a high degree of reusability and operational flexibility to assure significant improvement in space flight economy. Furthermore, Tug design must be compatible with Shuttle orbiter cargo bay size, weight limitations, and environment. For a ground-based system, consideration also must be given to Shuttle transport of a mated Tug/Payload.

1.2 OBJECTIVES

This point design study had one primary aim which was to be verified by design detail and analysis; namely, that a reusable, ground-based Space Tug with an IOC target by about the end of 1979 (1976 state-of-the-art) can carry a 3000-pound round trip payload between orbits at 100 nautical miles/ 28.5 degrees inclination and geosynchronous. The key constraint was use of a Space Shuttle having a 65000 pound orbital delivery capability. A minimum usable propellant mass fraction of 0.895 also was desired. Additional study objectives were to (1) define the necessary supporting research and technology (SR&T) activities and their associated funding, and (2) determine Tug development, first production, and maintenance/repair costs.

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1.3 STUDY SCOPE

The detail design of an integrated system was performed for a baseline concept. The concept was derived from MSFC's Study Plan and NR-selected materials, fabrication techniques, and subsystems resulting from currently available data and new trade studies.

Concurrent with the baseline study, options were evaluated having the potential for improving Tug mass fraction and mission performance. Emphasis was placed on the areas of alternate materials and subsystems, flight mode and operational variations, and use of advanced technology.

The study logic of Figure 1.3-1 depicts the major functional activities and outputs of these activities. The analyses performed to satisfy study objectives can be subdivided into three inter-related major efforts which started at study outset and ran concurrently to completion. Initiation of these efforts at the same time was made possible by the large amount of technical data available from the data bank. System requirements and criteria definition and program support gave the design definition effort the input data necessary for realistic structural, mechanical, thermal, and avionics subsystems design taking into account reliability and safety requirements. The three major tasks formed an iterative loop to the extent that the study schedule permitted. As the design of each component and subsystem evolved, the results were fed to the supporting activities which served to increase the depth of analysis and visibility of the overall system characteristics with each succeeding step. This approach also adapted itself to the timely establishment of performance sensitivities and development of potentially attractive subsystem concepts.

1.4 PROGRAM REQUIREMENTS

The planning data presented in this volume were prepared in accordance with the requirements defined in the NASA/MSFC Study Plan (Reference 1) and consist of the following principal elements:

1. Preliminary Plans

   Maintenance and Refurbishment
   Technology Development

2. Supporting Planning Data

   Manufacturing
   Test Operations
   Facilities
   Quality Assurance
   Program Development Schedule

The plans and supporting planning data describe a logical, integrated set of activities and events necessary to accomplish Tug mission and operational requirements. The time period covered by the planning data starts with NASA Phase A (Analysis) and ends during Phase D (Development/Operations) with an initial operational capability date in late 1980.

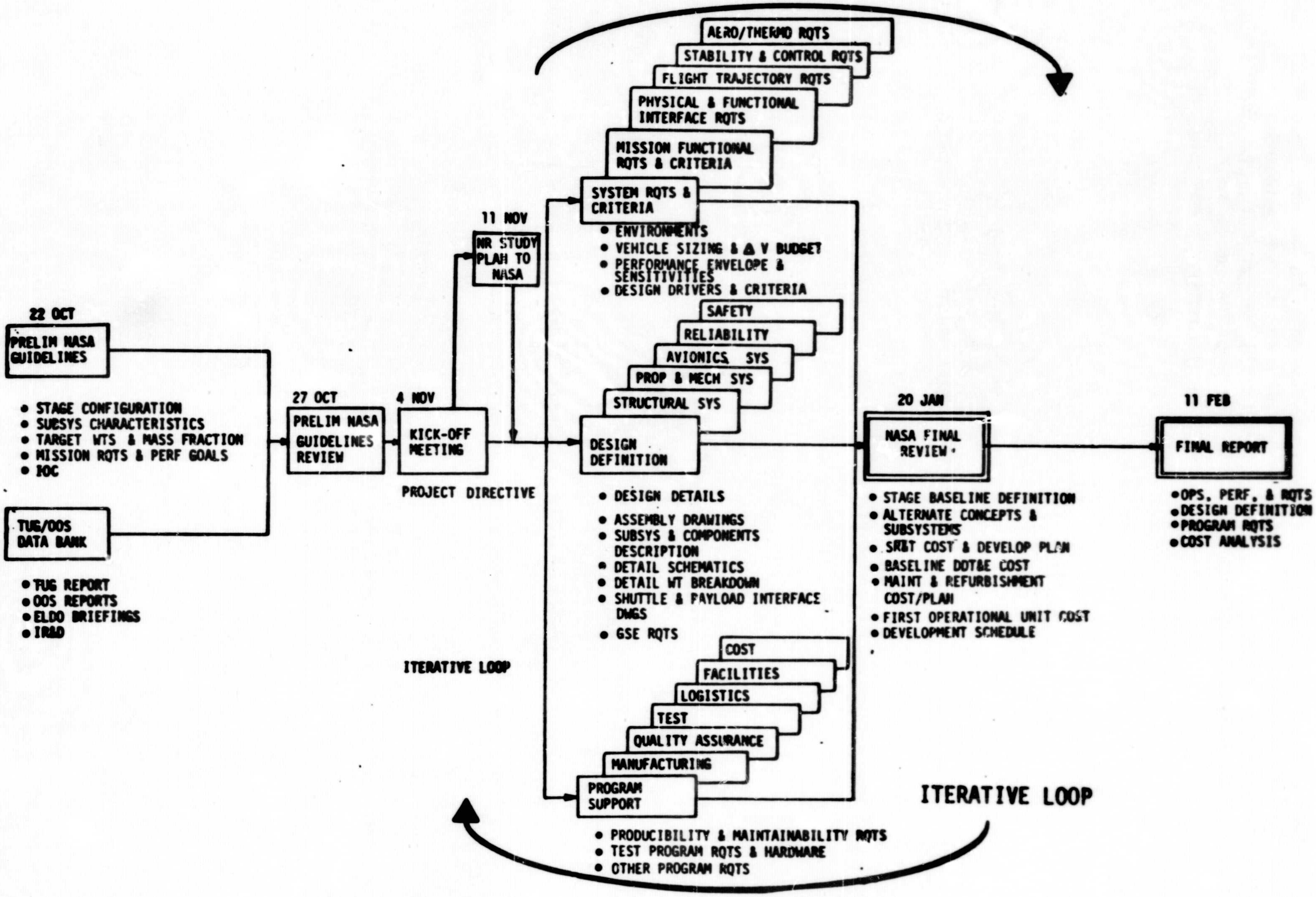

Figure 1.3-1 Top Level Study Logic

The plans and planning data are preliminary in nature, but sufficiently detailed to verify the Tug program approach and serve as the basis for schedule and cost estimating. The plans will be expanded and additional plans prepared as necessary during subsequent program phases.

REFERENCES

1. Tug Point Design Study Plan, October 25, 1971
P.D. Office, Program Development, MSFC

2. RST Study, MSC - Pre-Phase A Study for an Analysis of a Reusable Space Tug NAS 9-10925; Report SD 71-291-1 thru -6, 22 March 1971

3. NR OOS Study, SAMSO - Orbit-to-Orbit Shuttle (Chemical) Feasibility Study (OOS) Contract F04701-71-C-0171, 4 October 1971, SD 71- -1 thru -7; AF No. SAMSO-TR-71-238, Vol. I-VII

4. MDAC OOS Study SAMSO - Orbit-to-Orbit Shuttle (Chemical) Feasibility Study, Contract F04701-71-C-0173, SAMSO-TR-71-221

5. European Space Tug System (Pre-phase A) - MBB Group: BAC, SNIAS, ELLIOTT, SELENIA, ETCA

6. European Space Tug System (Pre-phase A) HSD Group: SLL, BELL, CAG, OSGMBH, ERNO, FIAT, FVW, SDD, SAEM, MSPA

SECTION 2.0

MAINTENANCE AND REFURBISHMENT PLAN

Maintenance and refurbishment is a function of the ground operations required to support the TUG mission objectives. The maintenance requirements identified in this plan were developed to the depth and degree permitted by data available.

Maintenance alternatives and tradeoffs were not formally conducted during this study. The approach selected was based on prior studies of space TUGS and other elements within the Space Transportation System. Additionally, maintenance requirements must be integrated with other support resources for operational effectiveness. The integration will optimize requirements for support equipment, test equipment, personnel number and skills, spares and repair parts, documentation, transportation.

Further refinement of the analysis presented in this plan will be accomplished on a continuing basis during the course of subsequent program phases. Through this iterative process, maintenance and support alternatives will be identified to achieve optimum operational effectiveness.

2.1 PURPOSE/SCOPE

The purpose of this plan is to provide a baseline for maintenance planning for the TUG ground operations support and to identify maintenance requirements consistent with design definitions.

The plan provides the concept for maintenance to be applied during the operational phase of the TUG Program. The maintenance analysis process to be utilized in defining requirements, tasks, and resources is described. The analysis considers the activities from the landing of the TUG within the Shuttle orbiter through the maintenance operations and terminates with integration of the vehicle with the EOS for the next assigned mission. Preventive and corrective maintenance functions are considered for the basic levels of effort, on the vehicle, component repair, and overhaul. Preliminary maintenance schedules have been developed and are included. A description of the maintenance requirements by vehicle subsystems is provided.

2.2 MAINTENANCE CONCEPT

The maintenance concept for the TUG system must be compatible with and in direct support of the planned mission objectives. The mission, briefly stated, is to deliver, retrieve and return payloads in orbits not available to the Space Shuttle vehicles. The TUG must be reused to be economically feasible. The maintenance concept and subsequent maintenance planning is an important factor in assuring the economic success of the program. Experience

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of airlines and related military and commercial programs has shown that maintenance and support may contribute 20 to 40 percent of the operational costs.

The TUG system maintenance concept is based on the same philosophy used by airline and military operations and planned for the Space Shuttle system. This concept emphasizes the application of on-condition maintenance, wherein subsystem performance is monitored and action taken when a degradation of performance is indicated. Experience has also shown that preventive maintenance, in the proper perspective, is a valuable method of improving availability. It will be applied to subsystem components that adhere to a wear-out mode of failure, such as mechanical and electro-mechanical devices. Maintenance scheduled for avionic equipment and other items having an extremely high MTBF would do more to degrade the basic reliability through human error and unbalanced circuitry. The goal, therefore, of the maintenance planning is to define those items in accordance with the foregoing concept and provide a proper balance of preventive and corrective maintenance.

Preventive maintenance is performed to retain an item in an operational condition through systematic inspections, adjustment, calibration, cleaning, replacement, checkout, etc., at established intervals. Corrective maintenance is the activity required to restore an item to an operational condition after a malfunction occurs.

Three levels of maintenance have been designated for the TUG system. The optimum utilization of personnel, equipment and other support resources are best achieved by this method. Expensive facilities and equipment are not duplicated. Personnel with specialized skills are utilized only when required to perform specific tasks. The three levels of maintenance are described as follows:

Level I Maintenance — All maintenance activities accomplished directly on system installed hardware. It includes on-vehicle fault isolation, component removal and replacement, servicing, replenishing, inspection, repair-in-place, and modifications. The Level I on-vehicle checkout cycle (Figure 2.2-1) combines a logic-functional flow approach to the checkout philosophy to be used during system inspections. Vehicle status data, inspection reports, and planned/phased maintenance requirements, are the basis for establishing system readiness. Scheduled maintenance, as required, will be performed in place or by spare replacement with the necessary checkout performed to ascertain subsystem readiness. When the subsystem is not functioning properly, corrective maintenance will be enacted by fault detection/troubleshooting methods to determine the problem. As the problem is defined, the action cycle (same as with preventive maintenance) will be activated with the necessary testing performed to assure system readiness.

Level II Maintenance — Those maintenance activities performed in direct support of Level I maintenance and will involve disposition or repair of hardware removed during Level I maintenance activities. It will be performed at maintenance shops equipped with special test and checkout equipment and in close proximity to line operations. Level II

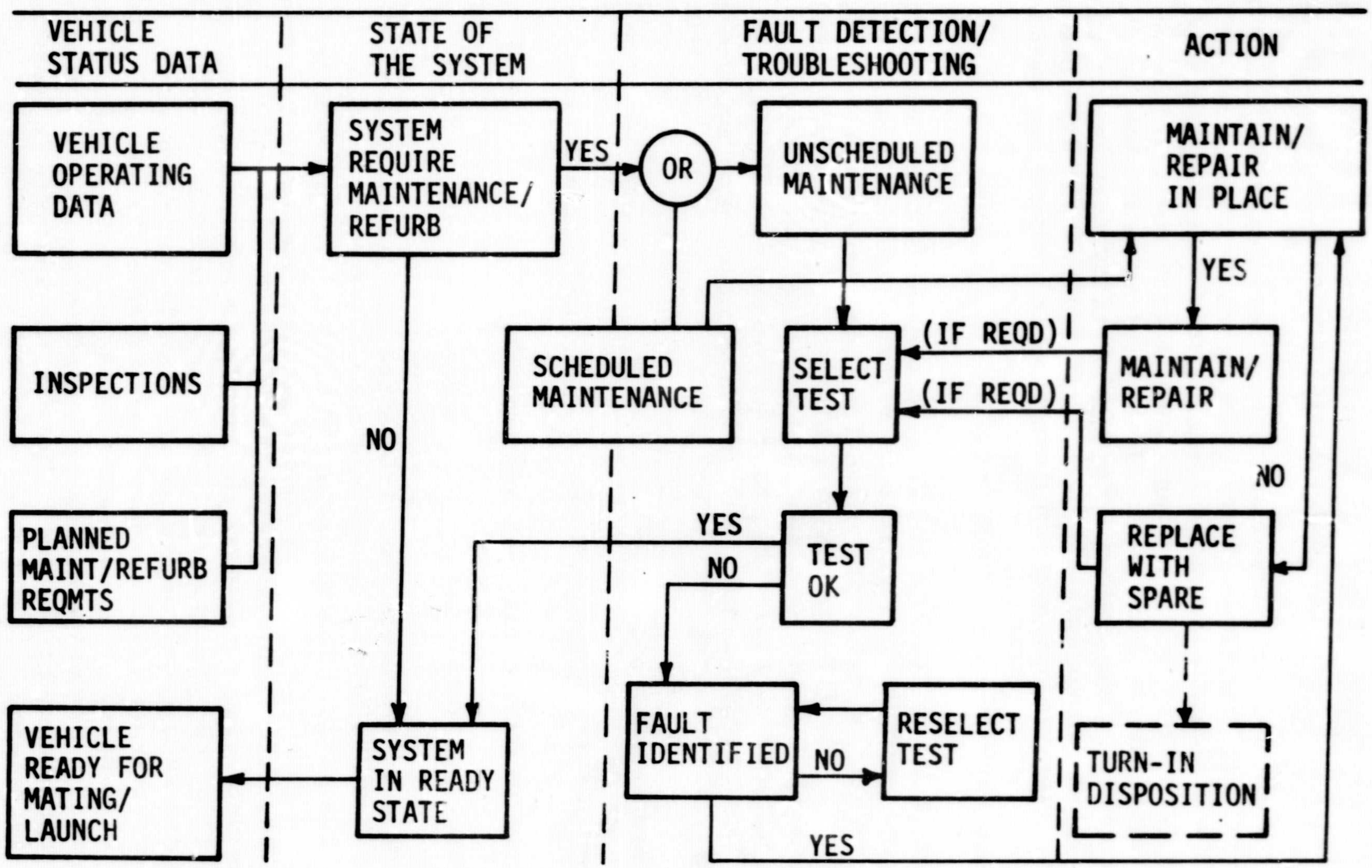

Figure 2.2-1 Maintenance/Refurbishment Logic Flow

maintenance will provide for the removal, replacement, repair, calibration, adjustment, checkout, test, and inspection of the lowest replaceable part consistent with the existing and planned facilities and capability available. Equipment modifications will be accomplished when justified by equipment availability and certification capability.

Level III Maintenance - Those maintenance activities performed in direct support of first and second level maintenance involving repair, overhaul, and modification operations will also involve disposition or repair of hardware removed during first, second and third level maintenance activities. It will generally be performed at remote locations, such as contractor and vendor factories or government repair and overhaul facilities where skills, tooling, facilities and data are available to repair, overhaul and modify hardware or to produce new hardware.

2.3 MAINTENANCE SUPPORT PROGRAM REQUIREMENTS

Maintenance support for the TUG Program considers those functions required from the time the TUG vehicle is returned to the landing site and post-landing operations are initiated to the time when the vehicle is ready for installation in the EOS for the next mission. A maintenance support program must provide a continuing analysis of actual performance and data to adjust the maintenance capabilities and requirements as necessary in addition to defining initial requirements. The TUG Maintenance Program, therefore, will consist of the following elements:

1. Maintenance Analysis

2. Definition of requirements for specific maintenance plans

3. Maintenance data collection and analysis

2.3.1 Maintenance Analysis

This analysis is a process that identifies the maintenance functions and requirements of TUG design and determines the most effective means to accomplish the functions. The maintenance functions for the TUG Program are depicted in Figure 2.3-1. From these functions and based on the maintenance concept, specific requirements and tasks can be developed to the lowest reparable component. The results of this analysis, when fully implemented, will identify all of the specific activities and resources necessary to satisfy the maintenance requirements of the vehicle and maintenance type (preventive, corrective), level, location and probable frequency. Subsequent iterations of the analysis will determine personnel tasks, support equipment, facilities, spares, consumables and data requirements, and will also follow component design and concept changes. The current analysis is constrained to maintenance functions.

The analysis process flow starts with a review of available design information (i.e., layouts, drawings, parts lists) in conjunction with established maintenance concepts and program ground rules and constraints. The program ground rules and mission objectives establish the basic

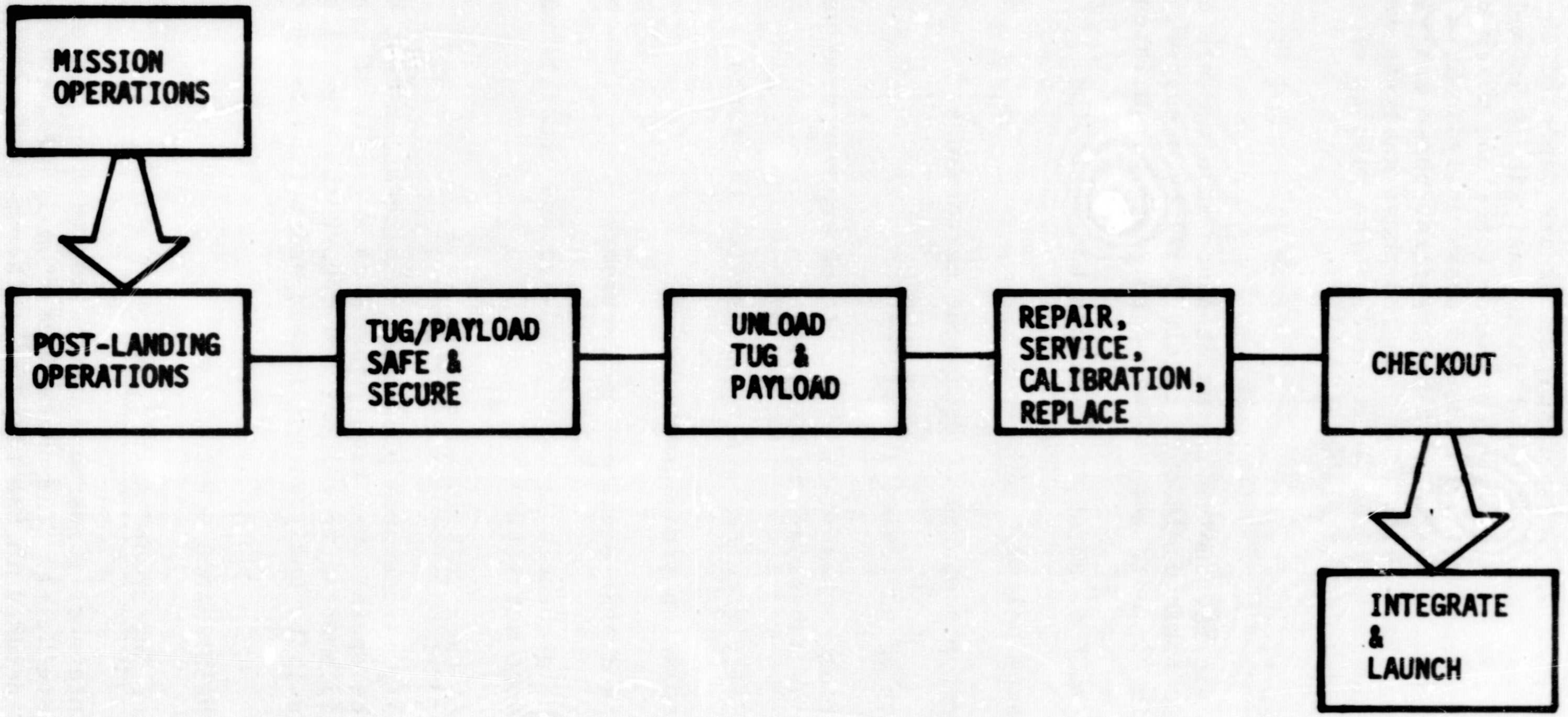

Figure 2.3-1 Maintenance Functions

maintenance requirements. These requirements are depicted in Figure 2.3-2, Maintenance Requirements. This first phase analysis is intended to ensure that no essential operational or maintenance function, which might generate a requirement, is overlooked. The second phase analysis is a more detailed evaluation and although an expansion of the first phase analysis is basically hardware oriented. The result of the second phase analysis is the tasks and times for ground operations and maintenance. The results of the complete analysis are provided in Section 2.4.

2.3.2 Maintenance Planning

When design begins, individual maintenance requirements documents, at the subsystems and replaceable unit levels, will be prepared. These documents will contain the detailed tasks and policies for maintenance performance.

Elements of each document will include the following:

1. Maintenance policy
2. Assessment procedures of equipment performance
3. Frequency of scheduled activities
4. Disposition recommendations for items removed from vehicle during Level I or subsequent maintenance
5. The facility requirements to accomplish the tasks
6. Fault isolation procedures
7. Support and test equipment requirements
8. Tasks and sequences for all scheduled and credible unscheduled maintenance activities

2.3.3 Maintenance Data Collection and Analysis

In the overall maintenance planning, consideration must be given to adjustments in the operational requirements as a result of experience. A system will be implemented to collect and report the significant maintenance data. The data will be analyzed for trends and action taken to revise requirements.

2.4 PREVENTIVE MAINTENANCE SCHEDULE

2.4.1 Maintenance Turnaround Activities

The TUG maintenance turnaround operations with projected time goals are presented in Figure 2.4-1. The operations from landing through post-maintenance are included in the timeline. The operations subsequent to this are controlled primarily by the Space Shuttle operations and related timelines.

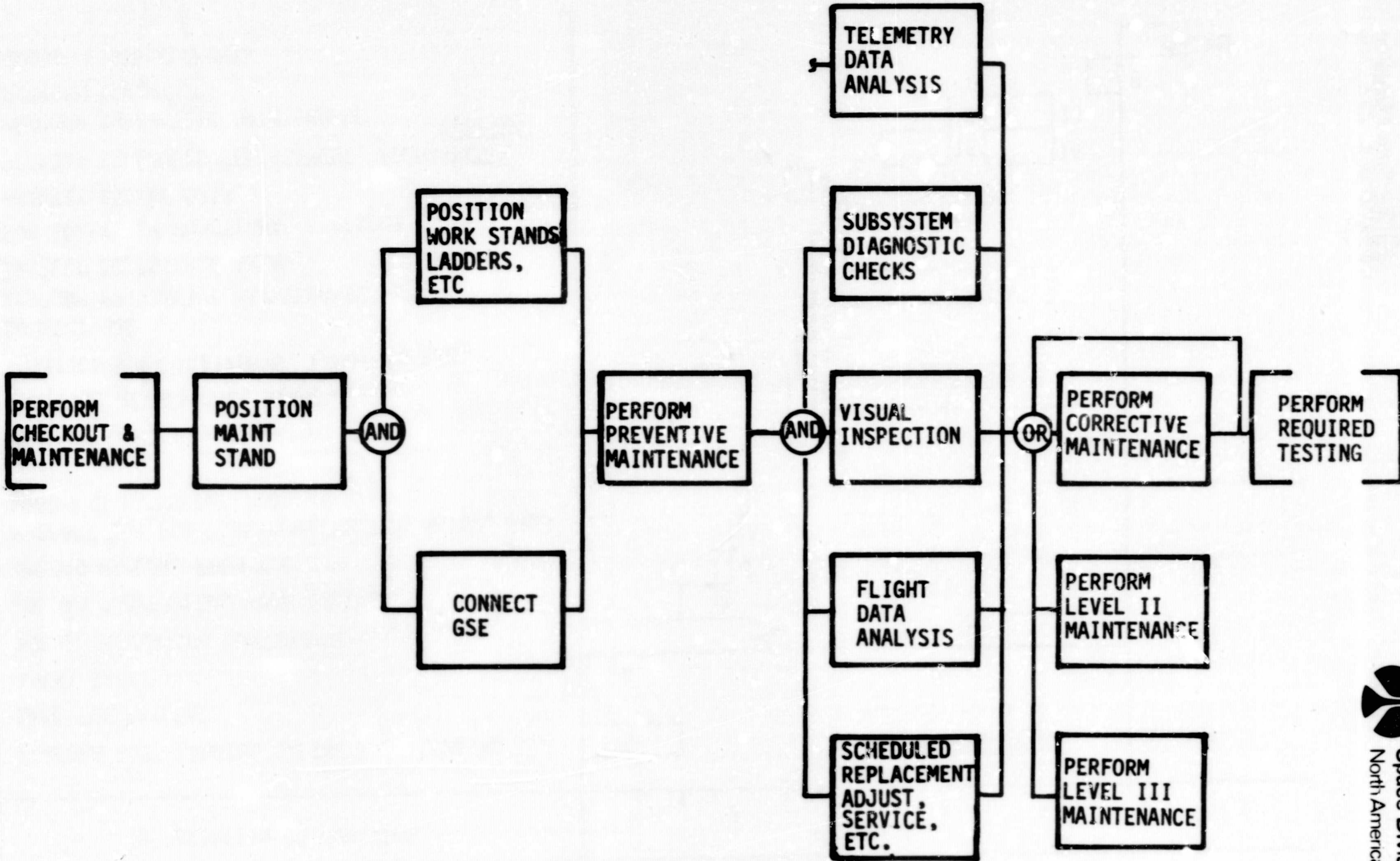

Figure 2.3-2 Maintenance Requirements

GROUND OPERATIONS TIMELINE

LANDING THRU MAINT.

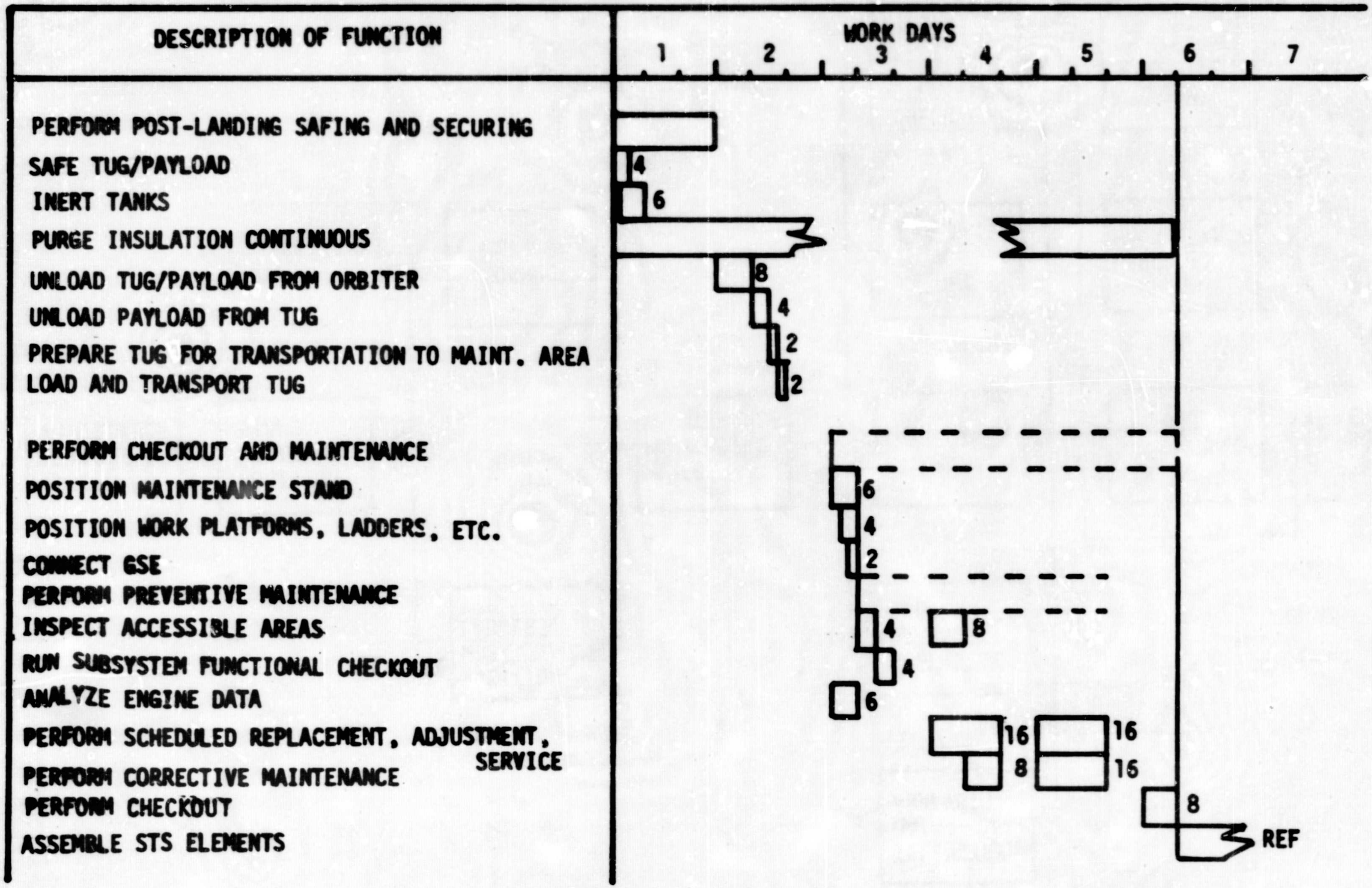

Figure 2.4-1 Ground Operations Timeline

After each mission specific maintenance will be performed, such as inspection, servicing and checkout. Corrective maintenance will be performed when determined necessary and identified by data analysis, inspection, and checkout of the subsystems. Table 2.4-1 lists by component the maintenance functions required for each turnaround cycle.

A description of the maintenance functions listed in Table 2.4-1, follows:

Inspection/Visual Check -- Inspection is concerned with non-destructive tests (NDT). Visual Check pertains to identification of physical characteristics before and after maintenance.

Adjust/Calibrate/Service — Adjustment is mechanically or electronically bringing an item to specified tolerance. Calibration is comparing an item with standards and correcting or adjusting as necessary. Servicing is the replenishment of consumables.

Clean/Purge — Cleaning refers to the removal of contaminants generally as an exterior function. Purging is the process of expelling unwanted fumes, vapors, or gases from a subsystem or assembly.

Checkout — A sequence of functional operations to determine the condition of a system or element thereof.

Composite Test — Test conducted to verify that the total system operating parameters are satisfactory after maintenance.

The frequency that these functions are accomplished is based on the functional operation of the items and predicted design life. In general, refurbishment of the components will not be required during the 20-mission life cycle of the TUG.

Postlanding Safing and Securing

The postlanding safing and securing operation includes the functions necessary to prepare the TUG for removal from the orbiter for subsequent maintenance operations. Ground service connections will be made and an inert purge will be applied to the tank insulation. Additional inerting and pressurization of tanks will be performed to totally inert the tanks.

Maintenance and Refurbishment (M&R)

The TUG is removed from the orbiter in the orbiter maintenance area. The TUG and payload are transported to the TUG maintenance area and preparation for M&R is initiated.

After the payload has been removed, the TUG is readied for maintenance. Access equipment, work platforms, stands, etc., are placed and access doors, panels, ports, etc., removed. Ground service connections are established as required. Parallel with these operations the engine flight data tapes are removed and analysis started to determine if any subsystem anomalies exist.

Table 2.4-1 (Sheet 1 of 3)
Required Maintenance Functions

Subsystem/Component	Maintenance Function					Frequency		Remarks
	Visual Check Inspection	Adjust/ Calibrate/ Service	Checkout	Clean/ Purge	Composite Test	Each Flight	Each ___ Flight	
STRUCTURE							5	NDT
Access Doors	X					X		
Tank Supports	X						5	NDT
Meteoroid Shield	X					X		
Docking Mechanism	X	X				X		
Tanks	X					X		NDT
PROPULSION					X	X		
Main Engine	X			X		X		
He Storage	X					X		
Valves	X			X		X		
Disconnects	X			X		X		
Sensors	X					X		
Flex Joints	X					X		
Auxiliary Tank	X			X		X		
Actuator	X	X				X		
Hyd Pump/Motor	X		X			X		
Regulators	X		X	X		X		
Pressure Switches	X	X	X			X		
Squib Valve	X					X		
Thrusters	X			X		X		
Gas Generators	X			X		X		
Turbo Pump	X			X		X		
Heat Exchanger	X			X		X		
Accumulator		X		X		X		

Table 2.4-1 (Sheet 2 of 3)
Required Maintenance Functions

Subsystem/Component	Maintenance Function: Visual Check Inspection	Adjust/ Calibrate/ Service	Checkout	Clean/ Purge	Composite Test	Frequency: Each Flight	Each ___ Flight	Remarks
AVIONICS					X	X		
Central Computer	X					X		
Data Acquisition Unit						X		
Interface Unit	X					X		
Measurement Pro. Unit	X					X		
Inertial Measuring Unit	X	X	X			X		Level II
Star Tracker	X	X	X			X		Level II
Horizon Sensor	X					X		
Autocollimator	X					X		
Back Up Gyro	X					X		
Back Up Rate Stab. Logic	X					X		
TVC/APS Electronics	X					X		
Laser Radar	X	X	X			X		Level II
TV Camera	X			X		X		
Docking Sensors	X					X		
Transponders	X					X		
Antenna	X			X		X		
Decoder	X					X		
Power Amplifier	X					X		
Transmitter	X					X		
Bi Phase Modulator	X					X		
RF Multiplexer	X					X		
RF Switch	X					X		
Instr. Sensor	X					X		
Signal Conditioner	X					X		
Fuel Cell	X	X	X	X		X		
Battery						X		Replace
Inverter	X		X			X		

Table 2.4-1 (Sheet 3 of 3)
Required Maintenance Functions

Subsystem/Component	Maintenance Function					Frequency		Remarks
	Visual Check Inspection	Adjust/ Calibrate/ Service	Checkout	Clean/ Purge	Composite Test	Each Flight	Each ___ Flight	
THERMAL					X	X		
Radiator	X					X		
Valves	X			X		X		
Insulation			X			X		
He Tank	X					X		
Regulators	X		X			X		
Cold Plates	X					X		
Heaters			X			X		
Disconnects	X			X		X		
Accumulator	X	X				X		
ORBITER INTERFACE					X	X		
Receiver	X					X		
Valves	X			X		X		
Regulators	X		X	X		X		
Disconnects	X			X		X		
Control/Status Panel	X					X		
Structure	X					X		
Support Mechanism	X			X		X		
Docking Mechanism	X	X		X		X		

Telemetry data received during the mission will be analyzed to identify potential maintenance requirements.

Inspection

Inspection of the TUG during maintenance will be by predesignated zones that are specifically related to access and servicing requirements. Specific requirements and final equipment locations will establish checklists for each area. Inspections will be augmented by non-destructuve evaluation where necessary. Each discrepancy noted during inspection will be documented, dispositioned, and analyzed for corrective action. The discrepancy record will be forwarded to the Maintenance Data Collection in addition to any other requirement.

Post-flight Subsystem Functional Checkout

After all discrepancies constraining checkout have been dispositioned, the ground services are energized. A checkout program will be developed for the ground computer system to provide a dynamic integrated subsystems checkout. Any discrepancies that require corrective maintenance will be compiled and scheduled to be performed with preventive maintenance and modification requirements.

Maintenance, Service, Repair, Modification

The schedule prepared for the total tasks will be used to perform the required operations. In-place calibration, alignment will be performed. Items requiring removal for alignment, such as the star tracker and IMU may be replaced with a new or spare unit depending upon the turnaround time for alignment. Thermal control accumulators will be recharged - repairs made as necessary and modifications incorporated as part of maintenance cycle. In the event that subsystems were disturbed as a result of repair, modification or replacement, a functional check will be performed of the affected subsystem. A composite test of the TUG will be performed to verify operating parameters.

Storage

If the particular vehicle is not scheduled for a mission, it will be placed in temporary storage. The vehicle will be provided with necessary ground services to maintain a controlled environment and insulation purge.

2.5 LEVEL I MAINTENANCE

2.5.1 <u>Functions and Requirements</u>

This section provides the subsystem maintenance functions and requirements for Level I activities. The Level I activities include inspection, servicing, fault isolation, malfunction correction, corrective action verification, checkout, and modifications. The maintenance functions are defined for the structural, avionics, propulsion, thermal, and orbiter

interface subsystems. Maintenance support resources required to accomplish these functions are identified in terms of personnel, training, data, support equipment and facilities.

The maintenance functions are defined for clarification and understanding of the terms used. The terms are listed in the sequence normally followed in the maintenance cycle.

Inspection — The examination, normally by visual or non-destructive means of vehicles and equipment to determine conformance to physical and structural requirements and to established standards.

Service — The replenishment of consumables and cleaning needed to keep an item in operating condition.

Fault Isolation — Actions involved in identifying and determining malfunctions in equipment by means of systematic analysis and checkouts.

Malfunction Correction — Maintenance performed to restore an item to a satisfactory condition by correcting a known or suspected malfunction or failure which has caused degradation of the item.

Corrective Action Verification — The inspection and checkout of an item to verify the action taken to restore it to a satisfactory condition has been successful.

Checkout — A sequence of functional, operational, visual inspections or calibration tests to determine the condition and status of a system or element thereof.

Modification — Alteration to the physical design of an item to correct a deficiency, facilitate production or improve operational effectiveness.

Replace — For the purpose of this study and plan, "Replace" will identify the requirement to replace unserviceable components and/or parts exclusive of disassembly or teardown of equipment. The replacement of items so identified will be based on limitation of total time, cycles and the relationship between age and operating reliability.

2.5.2 Structure Subsystem Group

The structure subsystem is comprised of seven major groups: LH_2 tank, LO_2 tank, thrust structure, forward skirt, intertank, aft skirt, and the docking mechanism.

The LH_2 and LO_2 tank structure is comprised of bulkheads, sidewalls, baffles, screens and screen supports, sumps, access doors, tank supports, and thermal protection system supports. The thrust structure provides the load carrying block supports. The forward skirt, intertank and aft skirt consists of frames, sidewalls access doors and meteroid protection structural elements. The docking elements include latching and actuating mechanisms.

The following functions will be performed as Level I maintenance on the structural subsystem group external surfaces and interior compartments.

Inspection

a. At each turnaround cycle, the accessible items within this group will be visually inspected for evidence of structural or thermal damage, corrosion, fluid leaks, and general security and integrity of components.

b. The docking mechanism will be inspected for evidence of wear, damage, and alignment.

c. Interior inspection of tanks will be performed if required by an indication of failure or contamination.

d. Inspection of all structural members, bulkheads, frames, panels, ribs, beams, etc., not visually accessible and critical load carrying elements will be subjected to non-destructive inspections (NDI) periodically or subsequent to unusual loading.

Repair

Discrepancies and other non-conforming conditions discovered during inspection will be corrected by repair in-place or by replacement. Shop and/or Level III maintenance specialists will support excessive structure repair if required.

Modification

Modifications will be performed as a scheduled activity in conjunction with normal maintenance.

The following support resources are required to accomplish the Level I functions previously listed.

Personnel — personnel with the following skills are required:

a. General vehicle maintenance

b. Structural maintenance specialist

c. Non-destructive test evaluation (NDTE)

Training — specific training relative to the structure and materials, safety, contamination control and certification of NDE personnel.

Spares — the spares requirements to support the Level I functions will include docking mechanism components, access doors and seals, thrust structure attachments, and meteoroid shield repair kit with replacement panels.

Data — The data required includes:

a. Procedures for visual inspection, alignment, servicing, and handling.

b. Readouts from the on-board computer to establish corrective maintenance requirements.

c. Repair and modification instructions will be required as the need arises.

Support Equipment — Equipment required for accomplishing routine Level I maintenance are:

Work stands	Alignment equipment
Transportation trailer	Protective covers
Handling slings	Cleaning equipment
NDT equipment	

Facilities — These requirements include:

a. Adequate electrical, pneumatic, and hydraulic sources for hand tools and equipment

b. Overhead crane for vehicle handling

2.5.3 Propulsion Subsystem Group

The propulsion subsystem includes the elements of: main propulsion; propellant feed, drain and vent; propellant management; propellant orientation; thrust vector control; pressurization; safing and venting; and reaction control.

Maintenance functions for the Level I activities consist of visual inspections, servicing, fault isolation and correction, LRU replacement, and checkout.

Inspection — visual inspection of the following items will be accomplished at each turnaround cycle:

a. Nozzle and external areas of engine for cracks, corrosion, hot spots, and structural integrity.

b. Engine pumps and other mechanical, electrical, and instrumentation devices for cracks, loose attachments, and corrosion.

c. LO_2 and LH_2 lines, manifolds, and fittings for corrosion, and loose attachments.

d. Regulator, relief, solenoid, check, pressure isolation, fill, drain, and vent valves for evidence of leaks, corrosion, loose attachments.

e. Gimbal actuators, reservoirs, pump, motor and attachments for leaks and corrosion.

Servicing

a. Engine control devices and mechanism will be mechanically operated to verify freedom of movement and proper adjustment

b. Structure, engine, and reaction thrusters will be cleaned of combustion deposits.

Fault Isolation — Malfunctions will be isolated to lowest level replaceable unit by review of data tapes, diagnostic tests and inspections.

Malfunction Correction — Level I maintenance will correct malfunctions by replacement of faulty unit or repair in place if possible (lines couplings, wiring, etc.).

Corrective Action Verification

a. Authorized repairs will be accomplished through established procedures with inspection approval of corrective action.

b. Verification of corrective action may be performed in conjunction with checkout.

Scheduled Replacement — Igniters and other age sensitive components will be replaced in accordance with established schedule.

Checkout — Prior to an engine firing or mission, the following checkout will be accomplished:

a. Engine leak check

b. End-to-end checkout prior to mating with orbiter of all command/control circuits.

c. Integrated subsystem functional test

Modifications — Modifications will be incorporated as a planned activity in conjunction with other maintenance.

The following support resources are necessary to accomplish Level I maintenance on the main propulsion elements.

Personnel — personnel with the following skills or classifications are required:

a. Rocket engine and system maintenance

b. Fluid system maintenance

c. Flight line maintenance

Training — Rocket engine theory, systems operation, propellant loading and utilization and engine control training will be provided for Level I maintenance personnel.

Spares — Spares to support Level I activities will be limited. Engines will be spared as an assembly. Replaceable components will be considered for spares procurement.

Data — The data required are:

a. Procedures for servicing, checkout and component replacement

b. Inspection requirements and criteria

c. Readouts from on-board system to identify corrective maintenance required

d. System description and malfunction isolation procedures

Support Equipment — Equipment required for Level I maintenance include:

Work stands	Engine removal/installation fixture
Engine transportation dolly	Service Equipment
Engine handling sling	Checkout Equipment

Facilities — Facility requirements include those necessary for spare engine storage and electric, hydraulic and pneumatic sources.

2.5.4 Avionics Subsystem Group

The avionics subsystem group is comprised of the following elements:

a. Data Management

b. Guidance, Navigation and Control

c. Rendezvous and Docking

d. Communication and Instrumentation

e. Power Generation

f. Power Conversion and Distribution

The Level I maintenance functions for the above elements are inspection, servicing, fault isolation and correction, checkout and modification.

Inspection

a. Visual inspection of the avionics group components will be required to determine evidence of damage, corrosion, grounding, degradation, security and overheating.

b. Inspection of wiring, plumbing and fuel cells for security, fluid leakage, insulation damage, and corrosion.

Servicing

a. Subsystems elements will be subjected to both individual and integrated calibration, alignment, or adjustment as required. Fluid system filters check or replaced.

b. Service fuel cell.

Fault Isolation and Correction

Subsystem and LRU's indicating degradation or marginal performance will be isolated during the maintenance cycle by analysis of flight data and support equipment. Malfunctions will be corrected by replacement, repair in place, or adjustment.

Checkout

Checkout of the avionics will be accomplished during post-maintenance tests. An end-to-end check will be performed.

Modification

Modifications will be performed as a planned activity in conjunction with other maintenance.

The following resources will be required to support the Level I functions:

Personnel — Personnel with the following skills or classifications are required:

a. Communications maintenance

b. Instrumentation and control

c. Checkout equipment analysis

d. Electrical maintenance

e. Fluid system maintenance

Training — Training of avionics support personnel will consist of subsystems interface, checkout, fault isolation and maintenance procedures.

Spares — To support Level I activities, spares will be necessary to support replacement of the following:

Batteries	Filters
Sensors	Floodlight
Fuel Cell	Switches
Antennas	Harnesses

Data — The types of data required for Level I maintenance are:

a. Procedures for checkout and inspection

b. Print-outs of on-board data tapes

c. Instructions for maintenance, servicing and modifications as applicable

Support Equipment — The type of equipment required to support the Level I activities are:

Ground Computer System
Computer Peripheral Equipment
Fuel Cell Slings
Power Distribution
Fluid Servicing

Facilities — Requirements for facilities to support Level I maintenance of avionics subsystems include electrical, fluid and gas sources for support equipment.

2.5.5 Thermal Subsystem Group

The thermal subsystem group consists of the fuel cell radiators, tankage insulation, insulation purge and repressurization, plume impingement insulation, and thermal control of components and compartments.

Maintenance functions for Level I activities consist of inspection, servicing, fault isolation and correction, LRU replacement, and checkout.

Inspection

a. Inspection of the radiator lines, fittings and valves for leaks and loose attachments.

b. Insulation repressurization and purge components (valves, disconnects, regulator, tank, etc.) inspected for leaks and loose attachments.

Fault Isolation

Isolate malfunctions to faulty LRU's for corrective maintenance.

Correct Malfunction

Replace faulty items and repair in place of wiring, plumbing and insulation.

Servicing

Servicing of this group will require calibration/adjustment of moisture sensing devices in multilayer insulation and filling of thermal coolant. Replacement/cleaning of plume impingement insulation, as required and service thermal control accumulator if necessary.

Checkout

Checkout of heaters, sensors and valves will be accomplished during post-maintenance checkout.

Modifications

Modifications will be incorporated as a planned activity with other maintenance.

The following resources are required to support Level I maintenance functions.

Personnel — Personnel with the following skills/classifications are required:

a. Fluid system maintenance

b. Insulation repair

c. Electrical/instrumentation maintenance

Training — Personnel listed above will require specific training relative to insulation material, evaluation, repair, and other subsystem functions and requirements.

Spares — LRU spares, insulation materials and repair kits will be required to support Level I functions. LRU spares include:

Isolation valves	Heaters
Moisture sensors	He regulator
Vent valve	Disconnects
Purge valve	

Data -- The data required to perform the Level I functions includes:

a. Procedures for inspection, evaluation, calibration, servicing

b. Repair and modification instructions as required

c. Readouts from data management subsystem

Support Equipment — Equipment required for accomplishing routine Level I functions are:

Coolant servicing
Sensor calibration/adjustment
Radiator handling equipment

Facilities — Facilities required to support Level I functions are electrical power, and a purge gas source.

2.5.6 Orbiter Subsystem Group

The orbiter subsystem group includes provisions for safing and venting, interface connections, orbiter support and docking structure.

Maintenance functions at Level I include inspection, adjustment, cleaning, purging and checkout as scheduled activities.

Inspection

All components within this group will be inspected visually to determine physical condition. Disconnects, support and docking mechanism will be checked to assure that no damage has occurred and the units are acceptable for continued use.

Adjustment

The docking mechanism will be adjusted as required.

Clean/Purge

Purging of fluid/gas system and cleaning of all interface surfaces will be accomplished.

Checkout

Regulators, valves, and other components will be checked to assure no leakage occurs and operating pressures are within tolerance.

Umbilicals will be checked to assure proper operation and condition.

Modification

Modifications will be performed as a planned activity in conjunction with other maintenance.

The following resources will be required to support the Level I functions:

Personnel — personnel with the following skills or classification are required:

a. Fluid System Maintenance

b. General Vehicle Maintenance

c. Electrical System Maintenance

Training — personnel listed above will require specific training relative to subsystem and component operational requirements.

Spares — replaceable units within the subsystem group will be considered for spares.

Data — The data required to perform the Level I functions include procedures and checklists for inspection, evaluation, repair and modification of the subsystem.

Support Equipment — Protective covers for interfaces

Service and checkout GSE

Facilities — Facilities required to support this subsystem include electric power and fluid and gas sources.

2.6 LEVEL II MAINTENANCE

2.6.1 Functions and Approach

The Level II maintenance function involves the repair, service, or dispositioning of hardware removed during the maintenance activities. The function is performed in shops equipped with test and checkout equipment. The eventual scope of the Level II activities and the manner in which they will be developed will be based on design, procurement, and reparable analysis of components. An effective capability, suitable to long-term requirements, envisioned for the TUG program, requires incremental development of facilities, equipment and personnel features. The Level II operations will be developed and implemented at the operating site consistent with the frequency of the operating demands and with the general proficiency buildup of the site maintenance operation.

During the test program, limited shop maintenance activity will be established for those components that require cleaning or adjustments, particularly components of ground support equipment. Consistent with facilities at the test site Level II shops will provide a build-up experience for the operational phase. Most vehicle components requiring repair during the test phase will be returned to the supplier or manufacturer to assure proper failure analysis and corrective action, as required.

The Level II maintenance shops will be established by the physical nature of equipment rather than by subsystem orientation. An economical approach would be combining the TUG Level II shops with the Shuttle or other programs operational at that time.

The Level II capability required is described in the following paragraphs:

Structure-Mechanical Equipment

Discrepant or damaged structural or mechanical parts of the TUG and ground support equipment will be repaired by fabricating and fitting minor structural parts and by reworking, straightening or strengthening structural elements. Replacement of detail parts will be accomplished.

Propulsion Equipment

Replaceable units of the propulsion, propellant, cryogenic subsystems removed from the TUG vehicle or ground support equipment found discrepant during inspection or checkout will be removed and sent to Level II maintenance area. Fault isolation and repair will be accomplished at the maintenance area. Repairs will be accomplished by replacement of subassemblies and parts, the adjustment/calibration and verification of the units prior to reinstallation in the vehicle or spare engine or assembly.

The Level II propulsion shop will be responsible for engine build-up to prepare replacement engine for installation. Removed engines will be processed through this shop for return to the Level III maintenance position, when required.

Avionics Equipment

Discrepant units of avionics subsystem will be routed to the Level II shops for fault isolation, repair and return to the subsystem or spares status. Diagnosis of malfunctions and verification of repair action will be accomplished by standard shop equipment augmented by whatever special equipment necessary. Repair will be completed by replacement of the most readily replaceable assembly level. Following repair, the operating condition of the unit will be verified and appropriate adjustments made to specification requirements of subsystem application.

After each mission the star tracker, laser radar and inertial measuring unit components will be removed from the vehicle and moved to the Level II shop for alignment and checkout.

Thermal Equipment

Many units of the thermal subsystem will be processed through the propulsion or structure shops for repair, modification and verification. The unique units within this subsystem, such as the multi-layer insulation, cold plates and heaters are within the planned Level II shop capability.

Interface Equipment

As with the thermal equipment units within this subsystem will be repaired, modified, verified without difficulty in structural, propulsion, or avionics shops.

2.7 LEVEL III MAINTENANCE

2.7.1 Function and Approach

Maintenance Level III consists of those activities in support of the first and second levels. Level III may involve disposition of hardware removed during the other levels or may involve the major repair or overhaul beyond the capabilities of the second level maintenance shops.

Level III functions will provide the skills, tooling, facilities and data to produce new or replacement hardware after the production phase of the program. The capability may be at the prime contractor, associate contractor, subcontractor or supplier.

The Level III capability will be developed incrementally during test and early operational phase to ensure adequate support after completion of production requirements.

As the operational phase progresses and production requirements diminish, actual maintenance activities will be analyzed and Level III resources allocated or adjusted. It is anticipated that the complexity of specific equipment and economic considerations will require maintenance, repair, or modification to be accomplished at the original manufacturer.

A typical functional flow of Level III maintenance is depicted in Figure 2.7-1.

Preliminary analysis of the equipment types indicates that the following activities will be performed at the Level III maintenance facilities.

a. Test, teardown, and evaluation

b. Replace discrepant subassembly and/or detail components

c. Fabricate replacement parts and modification kits

d. Functional tests

e. Clean, package and return to stock for future requirements

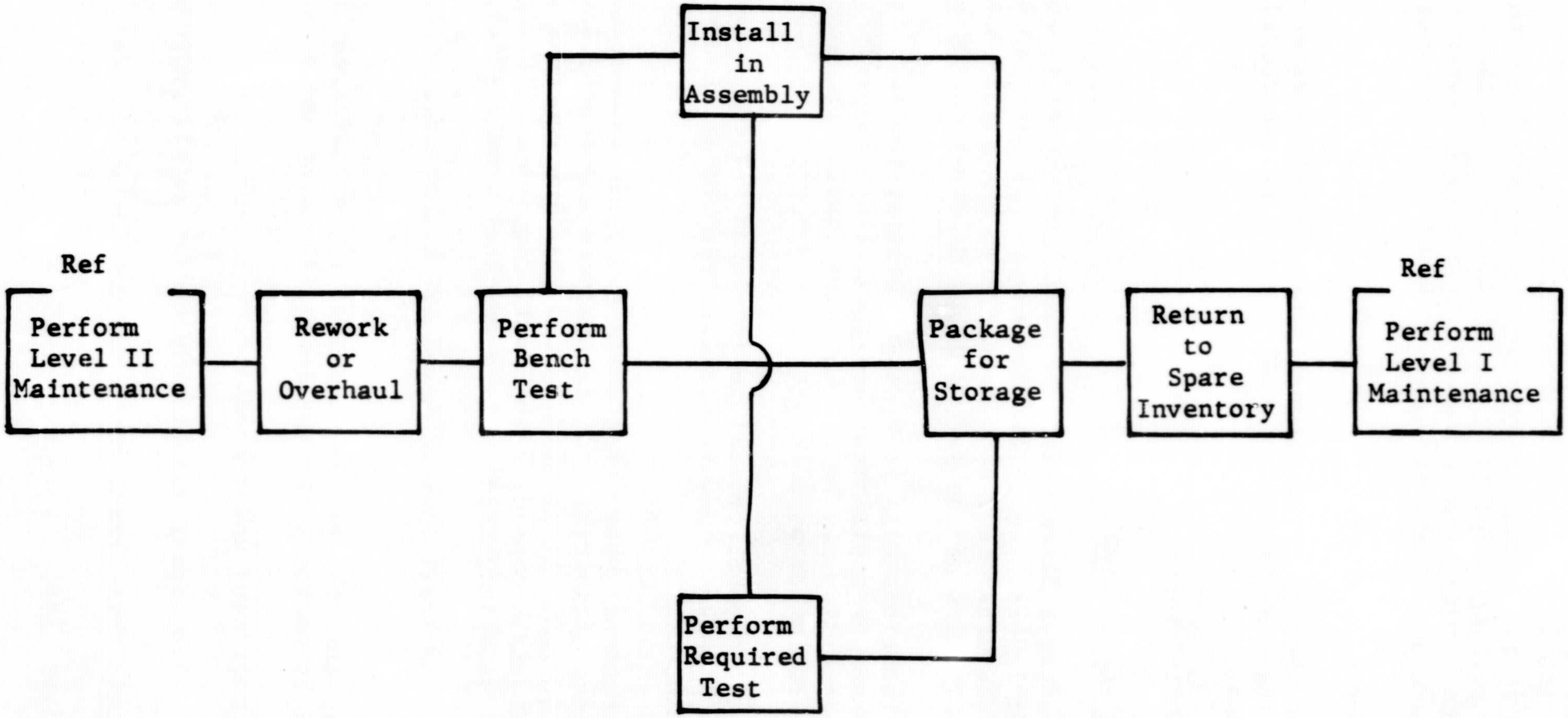

Figure 2.7-1 Functional Flow of Level III Maintenance

SECTION 3.0

TECHNOLOGY DEVELOPMENT PLAN

3.1 INTRODUCTION AND SUMMARY

3.1.1 PURPOSE/SCOPE

The purpose of this portion of the Tug Point Design studv final documentation is to identify the Tug development program items which need special technology development attention. This situation can arise because current system/subsystems technologies may be inadequate, requirements for more advanced technologies have not been identified previously, or current technology efforts need reorientation, any of which may require specific effort separate from the mainstream vehicle phased development program to insure timely availability of the necessary technology or equipment.

These areas of technology need are categorized generally into four sections: structures, materials and dynamics; propulsion and thermodynamics; avionics; and Tug/Earth Orbital Shuttle (EOS) Integration and Mission Analysis. The first portion to follow is concerned with the technologies needed for the baseline design (described elsewhere in the final report) which utilizes 1976 technology (i.e., the technology utilized is such that the equipment has been developed so final article procurement can be instigated at that time). The second portion discusses the implications of using post-1976 technology and optional/alternative technology.

3.1.2 BACKGROUND

In early 1970 in-house NR preliminary Tug studies it was presumed that the then current EOS systems technology base of approximately 1972 would also be appropriate for Tug. A good deal of commonality in systems hardware was also anticipated. This was appropriate considering that the estimated orbital payload of the EOS was then on the order of 75,000 - 100,000 lbs. The 1970-71 feasibility study of Reusable Space Tug (NAS 9-10925) for MSC utilized this technology level. Later, in the USAF Orbit-to-Orbit Shuttle (OOS) feasibility study (1971), Contract AF 4701-71-C-0171, the EOS payload capability was "groundruled" as 79,500 lb. Again, at this level of EOS performance, a 1972/73 technology level was found adequate and feasible for OOS. (The impact of more advanced technology, 1976/77, was also determined as one of the tasks in this study.)

Late in 1971 it was apparent that the EOS orbital payload capability might be no higher than 65,000 lb for the Tug plus its payload and installation provisions. Previous studies showed that this level of payload performance immediately places a tremendous pressure on the Tug for extremely high

performance/low inert weight. Consequently, it became apparent that the use of an early (1972/73) technology base or level was no longer appropriate nor adequate for Tug. This MSFC-sponsored Tug Point Design study was structured to provide a realistic feasibility assessment of a Tug designed to the more advanced 1976 level of technology to perform its required missions with an initial gross weight of less than 65,000 lbs. This level of technology is appropriate in that it is the latest technology level which would permit Tug operation in 1980.

3.1.3 APPROACH

In generating supporting technology requirements the design effort conducted during the Point Design study was reviewed to determine the technology support required. This design approach has been, in general, to synthesize systems designs utilizing the most advanced technologies anticipated to be available in each area by 1976. This approach yielded a detailed point design concept which meets all design constraints and exceeds the target performance goal. Thus, the feasibility of a 1976 technology design has been justified with some margin. An additional facet of the study approach was to determine the requirements for technologies which are not necessary within the framework of the baseline design but which could be utilized for still further weight margin or for other gains such as operational convenience, simplicity, reliability, confidence level, or cost.

Each recommended technology development item is described first as a problem, then the objective and approach of the estimated development study (or hardware test) effort required is outlined. The cost and schedule is then related to the main Tug program development phasing which is in turn placed upon an arbitrary calendar time scale which reflects data supplied by NASA.

Two other types of development tasks are identified for possible consideration in future studies. The first consists of alternate concepts that were not selected for the baseline Point Design Tug because either existing items or those already under development could fulfill the requirements, or specific ground rules would be violated. However, these alternates could provide reduced weight, reduced cost, higher performance, or other benefits if they were to be developed and utilized. The second type consists of tasks that could be expected to take place within the normal program development phases but are considered of sufficient importance to be called out or flagged for special attention to insure their future consideration.

An overall summary of the SR&T recommended items follows.

3.1.4 SUMMARY

General

Results of the Point Design study clearly show that the performance/weight objectives can be met with considerable margin for weight growth using 1976 technology. Therefore, the successful outcome of a development program can be confidently predicted. Alternately, this margin could be converted into alternate modes/capabilities.

Careful attention to Shuttle/Tug interfaces and integration will be necessary to insure physical and operational compatibility and near-optimum performance of each element. See Figure 3.1-1.

Structures

Use of graphite-epoxy composite material is believed to be feasible for Tug use and results in considerable weight saving. More information is required on material allowable properties and more experience is needed with fabrication of large panels. Research to obtain this data before 1976 is proposed.

The approach which allows moderate meteoroid penetration in the critical elements, propellant tank walls, which is related to the fracture mechanics characteristics, yields lightweight structural elements with adequate protection. Additional detailed information on fracture mechanics is required and a test program is presented.

The weight of cryogenic thermal protection was found to be relatively insensitive to the thickness of multi-layer insulation used. However, research is needed to establish methods of embossing Kapton, bonding Kapton to itself, coating with a non-corroding metal, developing a retaining tension membrane, and performing an overall system test.

Dynamic loadings are applied to the vehicle in docking and as a result of propellant sloshing. These dynamic loads can interact with the attitude control system and the development of computer programs are needed to establish 1) the effect of these interactions and 2) design criteria for design of the affected systems.

Propulsion

Items identified for research are zero-g venting, zero-g propellant acquisition, a prototype APS propellant conditioning unit, and electrically operated cryogenic valves.

Avionics

Requirements for avionics systems capability can be met utilizing technology available by 1976 including some electronics hardware adapted from the B-1 program. Research is proposed for computer software definition, laser radar rendezvous system requirements, rendezvous and docking simulation, and a computer program to optimize reliability and redundancy.

Tug/EOS Integration

Careful attention to Shuttle/Tug interfaces and interaction will be necessary to insure physical and functional compatibility and near optimum performance of each element. Research studies are identified to improve Tug performance through alternate operational modes.

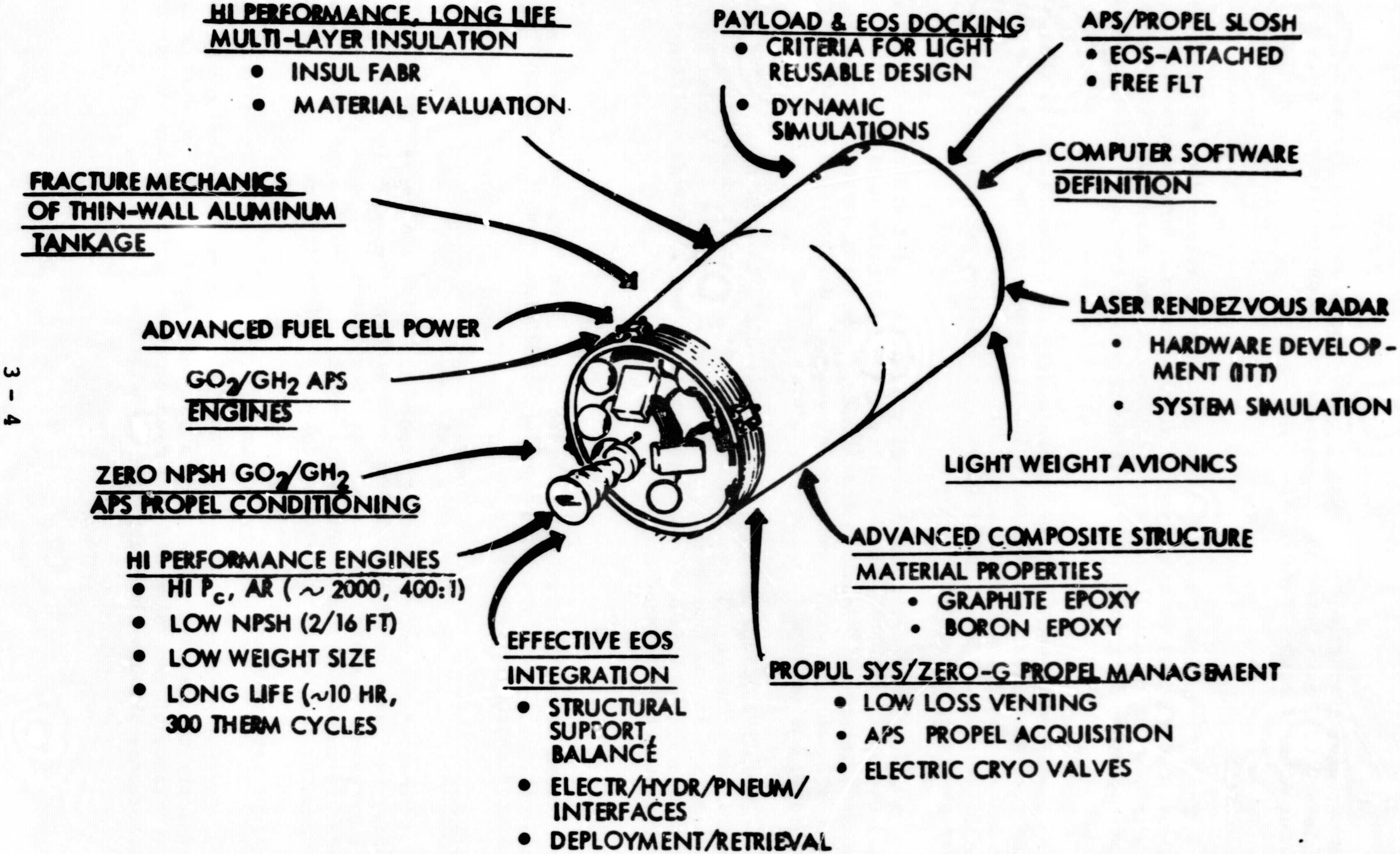

Figure 3.1-1 Important Research & Technology Tug Point Design Development Areas

Continuing Research and Technology

Current research on advanced engines, auxiliary propulsion systems, fuel cells, laser radar, and cryogenic insulation is very pertinent to Tug problems and helps to reduce development risk, or lends confidence in the program.

These key technology research programs on weight and performance sensitive components and subsystems must be continued but oriented to Tug conditions and groundrules as well as Shuttle.

Manufacturing

Current experience with composite structures indicates that there is reason for high confidence in the producibility of Tug. However, some confirming research is recommended on the manufacturing technique and mechanization for the large composite structure elements. This will assure adequate quality control with consistent, uniform properties such that minimum design margins will be feasible.

Facilities

Existing research, development, testing, and manufacturing facilities can be utilized if made available for the Tug development program at the proper times. Therefore, no technology advancement is needed.

Schedule

Figure 3.1-2 summarizes the schedule and cost of the identified SR&T study areas. These are shown in the context of the baseline Point Design Tug development schedule.

The timing of these efforts is thus dictated by the needs of the phased development program to which they are keyed.

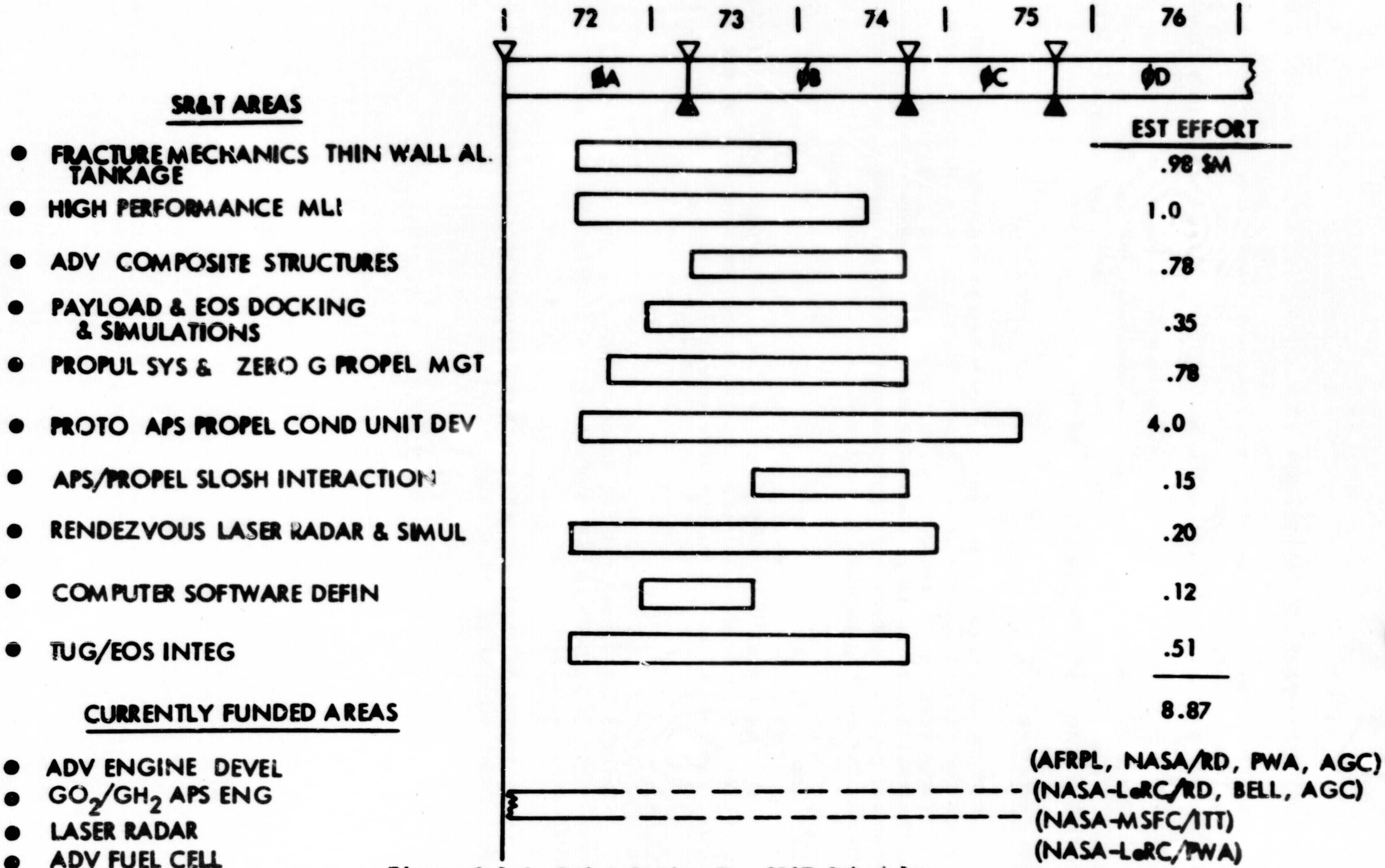

Figure 3.1-2 Point Design Tug SR&T Schedule

3.2 SUPPORTING RESEARCH AND TECHNOLOGY DEVELOPMENT REQUIRED FOR BASELINE POINT DESIGN

This section describes in detail those Tug-unique items identified as requiring special funding in supporting research and technology development for the Tug baseline point design. Only those areas not presently being funded are included. It is tacitly assumed that potentially applicable development items already being funded will continue to be funded adequately outside of this identified SR&T program. These items include development of main engines GOX/GH_2 APS engines, laser rendezvous radar hardware, light weight electronics, and advanced fuel cells.

This SR&T is divided into four categories:

Structures, Materials, and Dynamics

Propulsion and Thermodynamics

Avionics

Tug/EOS Integration and Mission Analysis

3.2.1 STRUCTURES, MATERIALS, AND DYNAMICS

The items identified for supporting research and technology development in the structures, materials, and dynamics area are:

Fracture Mechanics Material Properties for Thin Wall Aluminum Tankage

Advanced Composite Structure Material Properties

Advanced Composite Structure Manufacture and Test of Large Component

Bonding of Polymide (Kapton) Film to Itself

Low Emissivity, Moisture Resistant Coating for Plastic Film

Processing Parameters for Producing a Permanent Embossment Pattern in Plastic Film Used for Multiple Layer Insulation

Calorimeter Test of Optimized Embossed Multiple Layer Insulation

Tension Membrane for Retention of Multiple Layer Insulation

105" Dia. Tank Insulation System Test

Computer Program to Evaluate Docking Concepts and Establish Docking Criteria (Structures and Dynamics)

APS/Propellant Sloshing Interaction

1. Fracture Mechanics Material Properties

Problem Statement. The fracture mechanics analytical procedures for selecting the material and determining the necessary skin thickness for the pressurized tanks require that three material properties be known.

K_{IC} - Critical plane strain stress intensity

K_{TH} - Stress intensity at which a given flaw will continue to grow under a sustained load

da/dN - Flaw growth rate for different cyclic variations in stress intensities (ΔK)

Utilizing these properties, it is possible to determine the largest flaw which could exist in a pressurized vessel after a proof test; and the amount of flaw growth which would occur during the operational cycles, such that no flaw growth would occur under sustained load and the flaw could not grow through the thickness of the material.

The material properties indicated above are available for many materials, including 2219-T87 and 2014-T651 aluminums being considered for the Tug vehicle. However, when dealing with very thin materials (less than 0.2 inches) the commonly accepted values of K_{IC} and K_{TH} are no longer applicable. The thickness of material being considered for the Tug design are generally less than 0.1 inches. Therefore, material properties (e.g., K_{IC} and K_{TH}) must be developed for the materials and thickness ranges being considered for use in the Tug vehicle.

Without this data it would be impractical to perform a fracture mechanics analysis of the propellant tanks. With no fracture mechanics analysis, it would be necessary to apply an additional safety factor to the propellant tanks to guard against failure resulting from undetected flaws. The impact of the resulting high safety factor would be an unnecessary weight penalty imposed on the Tug vehicle.

Required Effort. A fracture mechanics material properties test program is needed to provide sufficient data to enable the final selection of the propellant tank material and to establish material properties so that a fracture mechanics analysis of the final design can be performed. The program will involve obtaining data on at least two materials being considered for the propellant tanks and will include parent and welded metal testing to determine:

Failure Stress vs Initial Flaw Size for various flaw configurations (long, short, shallow, and deep).

Sustained Load Flaw Growth Threshold Stress vs Flaw Size for various flaw configurations.

Spot check of Flaw Growth Rate data (da/dN) to assure that existing data is valid in the thickness ranges being considered.

Note: Data will be obtained at room and cryogenic temperatures for three different thicknesses in the thickness ranges being considered.

Expected Results. Initial data received from the test program will be used to screen and select the material to be used in the design of the propellant tanks. Subsequent data will provide remaining information needed to develop the design curves required for performing a fracture mechanics analysis.

Results of the test program and subsequent analysis will dictate the proper operating stress of the propellant tanks. The data will also indicate which proof test, pneumostat or cryoproof, will be most effective in verifying structural integrity of the tanks. The final product of the program will be the ability to design an efficient lightweight propellant tank structure for the Tug.

Timing/Criticality. The development of the fracture mechanics material properties is considered essential to the Tug development program and critical in terms of selection of the material, establishment of realistic design margins and hence attainment of realistic propellant tank design weights. Consequently, the test program should be initiated before the Phase B system study so that material selection can be made during this phase. Complete fracture mechanics material properties, for the selected material, must be also made available at initiation of the Phase C effort so that final sizing of the propellant tanks can be accomplished.

2. Advanced Composite Structure Material Properties

Problem Statement. Extreme emphasis on low inert weight for the Tug vehicle design necessitates the consideration of advanced composite materials. Current technology, which is adequate for the Tug fabrication, consists of hand layup techniques in conjunction with some mechanized equipment used for flat panel layups and filament winding of tubular structures similar to that used in aircraft design. Since the aircraft industry is the major user of composite materials and is not concerned with cryogenic temperatures, sufficient data for reliable design allowables at cryogenic temperatures is limited. Consequently most of the cryogenic mechanical property data being used for the Tug design are based either on engineering judgment or extrapolated from limited cryogenic test data.

Another required area of investigation is the verification of the micrometeoroid protection of these composite materials in a space environment.

Required Effort. Design allowable data will be generated at room temperature and -300 F for boron epoxy, graphite epoxy and S-glass filament wound composites which are being considered for Tug. Properties to be determined include orthotropic values of F_{tu}, F_{cu}, F_{su}, E, E_c and G. The investigation will also evaluate effects of layup orientation, composite thickness, fastener attachment parameters (optimum hole diameter and spacing), and specimen configuration. Limited tests will also be performed to establish micrometeoroid protection capability.

Timing/Criticality. This research should be accomplished prior to the completion of the Phase B program study so that the influence on system design analysis and program costing can be evaluated.

3. Advanced Composite Structure Manufacture and Test of Large Component

Problem Statement. Due to the Tug's weight criticality, it is necessary to consider the use of advanced composite materials such as graphite-epoxy faces on aluminum honeycomb. Graphite composite honeycomb construction has been used in aircraft production for small panels such as wheelwell doors (4' by 5'), flaps (8' by 2'), and wing boxes (3' by 7'). A composite S-II center engine beam, 10 feet long, was recently constructed and tested, with results falling in the predicted range. However, no large composite structures have been built, and the verification of fabrication, inspection, and repair procedures for a large component such as the Tug skirt must be shown. A full-scale test is required to verify manufacturing techniques and structural performance of the thin gage, large diameter, honeycomb structure. Preliminary testing of small detail parts and coupons is also needed to establish joint strengths and bonding feasibility, and for extrapolation of material properties for use in other major components. These material property tests were identified in the preceding SR&T statement.

Required Effort. The requirement to study design approaches and fabrication procedures for advanced composite materials necessitates full-scale testing of a large component such as the Tug forward skirt. The skirt shell is 15 feet in diameter, 12 feet long, and made of 3/8" aluminum honeycomb core with 0.008" graphite composite skins. Stiffened frames, also of graphite composite, will be bonded to the shell. In a room temperature environment, the skirt will be loaded in axial compression to limit load, and in axial tension to ultimate load.

Expected Results. The test program will verify analysis methods from graphite composite assemblies and will evaluate current fabrication techniques, determining the feasibility of such procedures as modular construction, bonding of frames to shell, and construction of design details. Methods of repairing the structure will be established, and quality control standards will be reviewed and updated.

Timing/Criticality. The development of manufacturing procedures and verification on design and analysis methods is essential to the Tug program, so research and testing should be completed prior to the completion of the Phase B study.

4. Bonding of Polyimide (Kapton) Film to Itself

Problem Statement. During fabrication of multiple layer insulation systems it is necessary to join individual sheets of film together along the edges to produce continuous layers of film which will not shift during mechanical loading in service. Where polyester (Mylar) film is used, the edges of the film can be quickly heat-bonded together. However, where higher service temperatures are expected, as in the case of the Tug, it will be necessary to use polyimide (Kapton) film. Kapton film is thermosetting and is not heat-sealable. Therefore, some method must be developed for bonding Kapton film to itself.

To solve this problem, the duPont Co. manufactures a form of polyimide film, designated Kapton Type F, which is coated on one surface with FEP Teflon resin to produce a heat-bondable surface. However, this type of material is unsuitable for multiple layer insulation both because the weight of the Teflon resin coating causes an unacceptable increase in the insulation density and because metallizing the uncoated surface of the polyimide results in processing difficulties. For example, Teflon could contaminate the opposite surface of the film and prevent good adhesion of the metallized coating, or the heat-rise which occurs during metallizing could cause premature bonding of the film. Several different types of adhesives are recommended by duPont for bonding polyimide film. None of these adhesives is considered acceptable for fabricating cryogenic insulation systems because they all require either a heat cure for at least 20 minutes or a much longer room-temperature cure.

On the basis of the foregoing information it appears that the most acceptable method for bonding polyimide film to itself is to apply an FEP Teflon dispersion coating locally to cut sections of film where the material is to be bonded during fabrication and installation of the insulation. The material can then be heat bonded easily and quickly, using a conventional hand-operated heat sealer. The FEP Teflon dispersion coating can be applied to local areas of polyimide film either by spraying or brushing. Teflon coatings applied by this procedure do not adhere to film as well as commercially applied heat-bondable coatings which usually are heat-cured onto the film. However, these dispersion coatings do adhere well enough to remain intact during normal handling of the film in fabricating the insulation system, and following the heat-bonding operation the FEP Teflon can be expected to exhibit good adhesion to both film surfaces with which it is in contact.

Required Effort: Various quick-setting cements will be obtained and tested to determine their bonding strength and curing times when used to bond Kapton film to itself. Also various FEP Teflon dispersion coatings will be applied to Kapton films which will then be heat-bonded together at various temperatures, pressures and time intervals. The resulting heat bonds will be tested to determine their strength.

The efficiency of each of the bonding methods investigated will be determined at cryogenic, room temperature, and the maximum expected service temperature of 200 F. In addition, Eastman 910 cement and Devon Corp. "Zip-Grip" 10 cement which cures in a matter of seconds at room temperature, should

be tested as adhesives for Kapton film. Cements with appreciably longer curing times would increase fabrication time of the insulation system and would not be acceptable.

Expected Results. The test results are expected to identify both a quick-setting adhesive for Kapton film and a system for heat-bonding Kapton film. The adhesive-bond and heat-bond are both expected to be acceptable for service temperatures up to 200 F.

Timing/Criticality. Development of a procedure for bonding Kapton film to itself is necessary to assure proper fabrication of multiple layer insulation systems over liquid hydrogen tanks on the Tug. Therefore, the research should be accomplished during the Phase B study.

5. Low-Emissivity Moisture-Resistant Coating for Plastic Film Material Used for Multiple Layer Insulation

Problem Statement. Multi-layer radiation shields are necessary to minimize heat radiation to the cryogenic propellants utilized in the Tug. The plastic film material most widely used as multiple layer insulation for cryogenic liquids is normally coated with a thin reflective layer of pure aluminum metal. However, experimental data has shown that thin aluminum coatings are corroded by exposure to moisture and lose their reflectivity. This characteristic of aluminum coatings caused no difficulties in the past where flight vehicles were discarded after a single flight. However, in a reusable vehicle such as the Tug it is necessary to maintain a dry gas purge on any aluminum-coated plastic film insulation system throughout the life of the vehicle.

One simple procedure for eliminating this problem is to use a corrosion-resistant coating in place of the aluminum coating. Possible replacement coatings include gold and nickel. Nickel is considered as a possible candidate because it is less expensive than gold and because emissivity data (Reference: Purdue University's "Thermophysical Properties of High Temperature Solid Materials, Vol. 1") indicates that (1) gold may not have acceptable emittance characteristics at temperatures between liquid nitrogen and liquid hydrogen, and (2) even oxidized nickel may have low emittance characteristics at cryogenic temperatures. Unfortunately, to save money, most evaluations of gold coating emittance were conducted at liquid nitrogen temperatures, and it was assumed that the emittance is nearly the same at liquid hydrogen temperatures.

At this time, the best coatings for use in Tug are not known, nor is the best method for applying this coating known. Without this knowledge it is difficult to predict resulting performance, weights, and costs.

Required Effort. Gold coatings are to be applied to ½ mil thick polyimide (Kapton) film by spray application of various Engelhard organic/gold coatings which are subsequently decomposed by heat to leave a metallic gold deposit. (Preliminary evaluation of one Engelhard coating applied to Kapton by this method showed more uniform thickness than vapor deposited gold coatings.) Also both gold and nickel coatings are to be applied to Kapton film by both

electroplating and electroless plating. All of the Kapton film materials metallized by the foregoing procedures are to be evaluated to determine the coating emittances at room temperatures, at -320 F (liquid nitrogen), and at -423 F (liquid hydrogen). A special emittance tester will be required for this effort. Such a tester could be easily designed and built and should not be unreasonably expensive. As an example, the tester could be similar to the Arthur D. Little Co. emittance meter except (1) liquid hydrogen would be used in place of liquid nitrogen for certain of the tests, and (2) the test specimen would be made the cold surface and the black-body shroud the room-temperature surface for the cryogenic tests.

Expected Results. This test program is expected to establish a non-corrosive reflective metallic coating for use on plastic film used as multiple layer insulation for liquid hydrogen containers. The coating should cost much less to apply than the vapor deposited gold currently being evaluated as a reflective coating for Kapton.

Timing/Criticality. Development of an acceptable low-emissivity moisture resistant coating for plastic film material is necessary to assure the thermal heat loss characteristics of the Tug liquid hydrogen tanks comply with other design considerations. Therefore, the research should be accomplished prior to the Phase B study.

6. Processing Parameters for Producing a Permanent Embossment Pattern in Plastic Film Used for Multiple Layer Insulation

Problem Statement. The most efficient thermal insulation, per unit weight, for cryogenic liquid tanks consists of multiple layers of thin plastic film which has been metallized and embossed. The embossment pattern minimizes direct thermal conduction through the insulation by maintaining space with minimum direct contact area between film layers. Other types of multiple layer thermal insulation systems use flat layers of film or foil which are held apart with mechanical spacers that add additional weight/bulk to the insulation system.

The embossment pattern in plastic film material normally tends to flatten out when the film is exposed to elevated temperatures. Embossed polyester (Mylar) film loses embossment height during exposure to temperatures as low as 140 F. The loss of embossment height by plastic films depends on many factors which have not yet been quantitatively established. These factors include time and temperature used to produce the embossment pattern in the film, and the post-embossment exposure conditions of temperature and compressive load for specific time intervals. The generic type and the thickness of the film are also important factors. Since the multiple layer insulation used on the Tug will be exposed to 200 F in service, Mylar film is inadequate for this application.

The embossed shield material is procured commercially and the patterns utilized to date were chosen on basis of availability, but were not optimized to provide the best reflective surfaces. Recent procurements by NR have also demonstrated that suppliers cannot duplicate prior orders; therefore, successive batches are unpredictable.

Two problems relating to the material must be solved.

Phase I - Determine a better substrate material than Mylar and/or develop a superior embossing technique. Kapton film is believed to be the best available candidate material, but its ability to hold a deep embossment has not been shown.

Phase II - Analyze the commercial patterns provided by suppliers, determine how the patterns should be changed to provide optimum layer density, fabricate experimental patterns as determined in Phase I and demonstrate acceptability. A plan is needed to ensure commercial suppliers can produce the material with the optimized embossment pattern.

Required Effort.

Phase I - Polyimide (Kapton) film material, ¼ mil thick, is to be embossed at various temperatures up to 750 F for various time periods up to 15 minutes. The Kapton film is a good candidate because it has high temperature resistance and is available in relatively thin gages. Specimens of Kapton film embossed under each of several different conditions of time and temperature are to be measured to determine their embossed thickness and linear dimensions. The specimens are then to be exposed to a temperature of 200 F for one hour while under a compressive load of 0.1 psi. After cooling, the embossed thickness and linear dimensions of the specimens are to be remeasured and the effects of the exposure to temperature determined. The effect of 10 exposure cycles of 200 F for one hour under a 0.1 psi load is to be determined for the specimens by the same method.

Phase II - Samples of materials provided by various suppliers for prior programs will be analyzed to determine the number of peaks in the embossment pattern per unit area. Suppliers will be contacted to determine if other patterns are available. New patterns will be defined to optimize the depth of embossment and the number of peaks per unit area. Samples will be produced using the materials and techniques developed in Phase I. These will be tested to demonstrate acceptability. A plan will be set up to coordinate production of optimized pattern by commercial suppliers.

Expected Results.

Phase I - This test program is expected to establish processing parameters for producing an embossment pattern in Kapton film which will remain dimensionally stable during exposure to 200 F under low compressive loading. Kapton film was experimentally embossed at a relatively low temperature and did not have as deep an embossment pattern as is desired for multiple layer insulation film. However, the specimen did show that Kapton film can be embossed. Because Kapton is a thermosetting plastic, it can be expected to retain its embossment pattern better during heating than does Mylar, a thermoplastic material.

Phase II - The results of this program are expected to identify causes of discrepancies in prior studies. It is also expected that this program, when coupled with improved metallized coatings and commercial production techniques, will provide a superior insulation system with optimum thermal performance, low weight and simple manufacturing characteristics.

Timing/Criticality. Development of this embossing procedure is necessary in time to assure that the environmental conditions which will be imposed on the insulation system during purging of the insulation and reentry of the Tug from space will not degrade the embossment pattern. Therefore, the research should be accomplished prior to the end of Phase B study.

7. Calorimeter Test of Optimized Embossed Multiple Layer Insulation

Problem Statement. Recent studies and test programs at NR show that lightweight high performance multi-layer insulation systems can be produced utilizing commercially supplied embossed aluminized Mylar for reflective shields. These programs disclosed that best thermal performance occurs when natural shield density is 30 to 40 layers per inch. Substituting Kapton for Mylar raises the operating temperature limit from +140 F to approximately +300 F (as required for Tug).

Test programs were proposed in the preceding pages to optimize the embossment pattern and to develop techniques for embossing the Kapton material. Laboratory tests are proposed to verify the adequacy of the new pattern and procedures.

A calorimeter test is needed to verify thermal performance of a system utilizing the new patterns and material in the cryogenic environment.

Required Effort. After the optimized material becomes available, a test program will be conducted in which a guarded calorimeter will be insulated with the new material. It will be tested with LH_2 in a chamber capable of maintaining a vacuum below 10^{-4} torr.

Following the test runs in which structural integrity and thermal performance will be determined, the specimen will be clinically dissected. Coordinating data will be obtained from flat plate calorimeter.

Expected Results. This test program is expected to demonstrate thermal performance of the optimized embossed aluminized Kapton multilayer insulation system. The data will fill a hole in the technology. The system is expected to be extremely competitive with other concepts yet weigh less.

Timing/Criticality. Demonstration of this concept and material is necessary to assure proper selection of insulation system for Tug. Therefore, the program should be accomplished prior to end of Phase B study.

8. Tension Membrane for Retention of Multiple Layer Insulation

Problem Statement. A tension membrane fabric is required to prevent the structurally weak multiple layer insulation films from ballooning and bursting when purging the insulation or evacuating the air from the insulation during space flights. The tension membrane must be highly porous to airflow, lightweight, fatigue resistant, dimensionally stable at service temperatures, and have relative low elongation at service tensile loads. Although polyester (Dacron) fabric meets these requirements for maximum service temperatures below 140 F, it is dimensionally unstable at the Tug service temperature of 200 F. The reason for this dimensional instability is that Dacron must be heat-set to reduce its elongation under load, and heat-set Dacron shrinks considerably when heated above 140 F. A suitable alternate fabric is aromatic polyamide (Nomex) which often is called high-temperature nylon. Nomex fiber has an ultimate elongation of approximately 12 percent as compared to polyester fiber with an ultimate elongation of approximately 10 percent. However, the upper temperature limit for Nomex is approximately 500 F for 1000 hours and up to 700 F for very short time exposure. Nomex is not as commonly used as polyester, and hence the number of commercially available fabric weaves is much more limited. However, Nomex can be specially woven into any required weave configuration. It will be necessary to evaluate the various weaves of Nomex to establish the preferred tension membrane cloth.

Required Effort. Various commercially available weave constructions are to be obtained of porous and relatively lightweight Nomex cloth. Each weave construction is to be tested for airflow transmission rate, weight, service fatigue life, dimensional stability as a result of repeated exposure to 200 F, elongation under a load of up to 10 lbs/inch, and ultimate tensile strength in both the warp and fill directions. The lightest weight fabric which meets all of the minimum physical properties requirements for the Tug tension membrane cloth will be identified. If none of the fabrics tested meet the dimensional stability requirements for the tension membrane during repeated exposure to Tug service temperatures, the fabric is to be preshrunk by heating slightly above the service temperature or by immersion in 75 to 100 percent formic acid and then retested to determine the other physical properties of the cloth. DuPont claims that Nomex which has been shrunk by treatment in formic acid is completely dimensionally stable at temperatures up to 650 F.

Expected Results. This test program is expected to provide physical properties data on the commercially available Nomex fabrics. From this data sheet it will be possible to select the optimum tension membrane fabric for use as a protective cover over the multiple layer insulation used on the Tug.

Timing/Criticality. Although the tension membrane fabric will not be physically required until actual assembly of the Tug vehicle insulation system, the weight and porosity of the fabric should be accurately known during early design stages of the vehicle in order to optimize the design of the insulation system. Therefore, this study program should be accomplished prior to the completion of Phase B study.

9. 105 Inch Diameter Tank Insulation System Test

Problem Statement. Studies are currently underway to develop a lightweight high performance insulation system concept using commercially produced embossed aluminized Mylar for the reflective shields. It has been shown that performance can be improved up to 50 percent by optimizing and stiffening the embossment pattern. It was also shown that the shield material should be changed to Kapton if the system will experience compressive loads at temperatures in excess of +140 F.

Studies are proposed in previous pages to optimize the embossment pattern and to provide the procedures for producing the pattern in Kapton. A study is also proposed to permit small scale calorimeter tests on this material.

An additional study is required to extend the material development technology to large scale tests and to verify the insulation performance and weight. NR recommends the use of an existing tank such as the 105 inch diameter tank and test facility at NASA/MSFC (which is currently being used to test aluminized Mylar insulation) to minimize costs and to ensure compatibility in results with prior system tests.

It will be necessary to obtain sufficient satisfactory insulation material to apply to the large scale tank; develop the proper techniques for applying, inspecting, and repairing the insulation; and to conduct tests on the large scale tank to verify thermal performance of the installed insulation system.

Required Effort.

Phase 1 - From prior studies the optimized embossment pattern will be defined by the number of peaks per square inch, depth of embossment, shape of peaks, dips, etc. Process procedures for embossing the pattern on Kapton will be defined in terms of temperature of embossment process, time, chill rate, chill temperature, contact pressure, etc. Additional definitive materials properties data will be available from the prior lab studies.

Capability of commercial suppliers to repeatedly produce the material will be evaluated and adequate material obtained.

Phase 2 - An insulation system will be designed for the large scale calorimeter. An application model will be selected prior to start of the design. The insulation system design will be limited to the features necessary to evaluate the performance and determine operational characteristics of the materials and the concept.

The configuration will utilize natural lay spacerless configuration and will be oriented to provide maximum thermal performance with least weight penalty for the application model profile.

The insulation system will be installed by manufacturing personnel with normal quality control inspection. Records will be kept to enable evaluation of producibility of the embossed Kapton compared to other materials and concepts.

Phase 3 - After the insulation system is installed and checked it will be shipped to the facility selected for testing. Tests will be of sufficient number to ensure both thermal and structural performance characteristics are measured and evaluated.

Expected Results. This program is expected to result in definition of installation, inspection, and repair procedures for fabrication of light-weight high performance multilayer embossed insulation systems. Thermal and structural performance of the Kapton insulation system will be thoroughly evaluated with respect to other materials, combinations and concepts.

Timing/Criticality. Assurance of availability of these enhanced materials is necessary in time to permit selection of a high performance insulation system that will ensure minimum payload penalty to the Tug. It should therefore be complete prior to end of Phase B study.

10. Computer Program To Evaluate Docking Concepts and Establish Docking Criteria

Problem Statement. Docking criteria, such as impact loads and dynamics, must be established to design the Tug docking mechanism and other systems. Several docking concepts are being considered and the design criteria for each concept must be established for both EOS/Tug and Tug/Payload systems. In the final design, various concepts must be evaluated and tradeoff studies performed to establish the preferred concept. Within each concept, parametric studies must be made for various ranges of payloads and Tug weights.

The effects on both vehicles of initial conditions and physical constants of the system are the desired results of this docking study. Since a variation of all the pertinent parameters would be prohibitive, only the most important need be selected. The major parameters associated with initial conditions are the relative orientation and velocity at impact. The important physical constants are vehicle flexibility, compliance of docking mechanism, control system power, and the inertias of each vehicle. The variation of these parameters through which a successful docking can occur is defined as the capture boundaries of the system.

A computer program must be developed to permit system evaluation and design criteria establishment to proceed in an economical, timely manner. Present docking computer programs from Apollo, Gemini, and other studies are not directly applicable to Tug docking.

Required Effort. A flexible computer program will be developed in modular form to permit variations in Tug vehicle and docking configurations to be readily examined and the effects of those variations determined. Existing computer programs and subroutines from Apollo, Gemini, and other studies will be examined and, where applicable, will be used directly, modified, or supplemented with additional components.

Expected Results. A computer program which can determine the time variation of forces, moments, displacements, velocities, accelerations, and the total attitude change of the two docked vehicles will result. Active damping rate control schemes can be added to the system, so that requirements for stabilization and control of Tug during docking can be determined. The computer program will also be capable of determining the capture boundaries of the system.

Timing/Criticality. This development is considered essential to the Tug development program and critical in terms of designing a docking mechanism. Consequently, the study should be accomplished prior to the completion of the Phase B study.

11. APS/Propellant Sloshing Interaction

Problem Statement. When the Tug is deployed from or retracted into the Shuttle cargo bay, the propellant will start to slosh. This sloshing will apply dynamic loadings on the Tug and its supporting mechanism and design criteria to accommodate the sloshing must be established. If the Shuttle uses a remote manipulator, the long lever arm would make sloshing and oscillations even more critical. During any quiescent period when the Tug is in free drift, the propellant mass distributions can have many conceivable positions. When a thruster jet is fired, new mass distributions will result. The transition mechanism from one fluid state to another is also unknown. This transition mechanism is needed to design a compatible attitude control subsystem so that the sloshing and the thruster firing will not build up the kinetic energy of the dynamic system promoting diverging vehicle oscillation. Likewise, during docking, the impact will cause the propellant energy state to change. This transition mechanism must be understood for designing the rate damping mode of the ACS.

During attitude hold, the periodic firing of thrusters will cause the propellant to oscillate with the thruster firing frequency in some modified manner. It is desired to determine the amplitude and phase relationship between jet firing and fluid slosh. These data are needed to determine the upper and lower bounds for jet size and acceptable limit cycle frequency.

When the main engine is shut down, the propellant will continue to move and impart dynamic loadings to the vehicle. The effects of these loadings and the forces required by the ACS to stabilize the vehicle must be determined.

Required Effort. The required study efforts are as follows:

Review literature on sloshing dynamics and determine missing data and theory.

Develop equations of motion for confined sloshing mass, using finite elements approach.

Develop digital computer program for numerically integrating the equations of motion. Include external forces and torques due to the control system, docking impacts, and rate of swing out or manipulator motions.

Run computer program and determine interactions between slosh dynamics and external influences (rates, forces, and moments).

Evaluate computed results and compare with existing slosh models.

Deduce conclusions and modify or improve math models accordingly.

Expected Results.

Threshold level of turning rate, force, torque, and impact at which a given geometry of sloshing fluid would cause sustained slosh oscillation.

Slosh attenuation parameters and sensitivities.

The extent to which a given sloshing situation would impact design constraint, attitude control and docking performance.

The limiting rate at which the manipulator should be moving the Tug during berthing.

Timing/Criticality. These results will be used as design criteria and constraints to be imposed on Tug structure design, control design, docking design, and shuttle remote manipulator design. Since the slosh dynamics imposes design constraints to these subsystems, the above effort should be performed prior to completion of Phase B.

3.2.2 PROPULSION

In the propulsion area, the items identified for SR&T primarily involve propellant handling. Currently funded study efforts such as development of the main engines and GO_2/GH APS engines are assumed to be continued and are not included in this list. The development of a prototype APS conditioning unit is the single largest item in the SR&T program. The items identified are:

Zero-G Venting

Zero-G APS Propellant Acquisition System Technology

Auxiliary Propulsion System Propellant Conditioning System

Electrically Operated Cryogenic Valves.

1. Zero-G Venting

Problem Statement

In a low gravity environment, the containment of a cryogenic liquid is complicated by the lack of positive control of the position of the liquid and gas phases. Either the generated vapor must be vented or incoming heat must be removed from the gas and liquid phases to control the tank pressure. Potential problems associated with venting a propellant tank under conditions of reduced gravity are loss of propellant by boil-over due to liquid level rise, and loss of propellant by entrainment of liquid in the vented vapor. Removal of incoming heat from both gas and liquid propellant phases requires the use of ullage and liquid temperature stratification mathematical models which will yield valid results under conditions of low gravity.

Two systems were considered for control of the Tug internal thermodynamics. These are (1) a thermodynamic vent heat exchange system and (2) direct overboard venting. The thermodynamic vent heat exchange system includes an expansion valve where LH_2 is throttled to a relatively low pressure and temperature. This provides the necessary temperature differential for extraction of heat from the propellant by an appropriate heat exchanger. Direct overboard venting using low g thrust during the venting operation as proposed for Tug has been experimentally confirmed during tests of an orbiting Saturn S-IVB LH_2 tank (AS-203). However, reliable analytic procedures have not been developed for this venting.

Required Effort

The feasibility of the basic thermodynamic vent heat exchange system concept has been experimentally established. In addition, several technology studies provided additional data and current studies will soon provide more data. Experimental one-g tests for simulation of the low gravity internal tank thermodynamics for a cryogenic propellant are required. Also, analyses should be performed to assess the effects of variable-g fields on the propellant thermal stratification which could be induced by inertial attitude orientation. Therefore, both analytical and experimental data will be available for use in evolving workable designs. The effort then would be to develop specific test plans and monitor and evaluate the results of all the technology studies and experiments related to thermodynamic vent systems, both ground and flight tests.

An empirical model for predicting liquid level rise due to boiling during direct overboard venting will be required for design purposes to preclude liquid boil-over during venting operations. Also, it will be required to predict the maximum venting rate than can be scheduled for a rapid blowdown of a cryogenic tank. To date, there is no quantitative data of liquid level rise during venting in a low gravity environment. A successful design of a cryogenic tank incorporating pressure relief venting depends on the availability of such information. Therefore, experiments should be performed which will provide empirical relationships to predict ullage temperature stratification and liquid level rise under low gravity during a venting operation. A phenomena which is not understood or predicted is the interfacial breakup of

the liquid into globules in low gravity. Forces which are negligible under one-g have been observed in AS-203 films to cause globules to be thrown into the ullage and possibly out through the vent system. An experimental study to define size and velocity of the globules as a function of forces and gravity level is required. The effects of the unbalanced thrusting from venting liquid may exceed the significance of the mass loss. An evaluation of interfacial forces such as sloshing and inertial forces related to emerging bubbles should be examined.

Expected Results

The results of the direct overboard venting study would be an experimental and analytical model to predict liquid level rise during venting and ullage and liquid temperature stratification under low gravity. Additionally, an empirical model would be required for predication of the interfacial forces that exist during venting and the globule size and velocity that results from these interfacial forces.

Timing/Criticality

The two study efforts should be completed prior to the end of Phase B. These efforts are critical to the efficient design of a zero-g venting system in terms of system weight, operational simplicity, and mission adaptability.

2. Zero-G APS Propellant Acquisition System Technology

Problem Statement

The Tug APS requires a supply of bubble-free liquid propellant during prolonged coast periods. The current design concept of an auxiliary tank with a screened refill port and a system of internal screened tubular collectors rests upon a sound theoretical basis but much more experimentally obtained empirical data are needed. A low level of technology development in this area has been pursued for the past 12 years but is inadequate for Tug design. Most operational and experimental emphasis has been on Earth storable propellants since all zero-g provisions have used these propellants. (The SIV-B utilizes continuous propulsive vent settings and the restart operational experience from Centaur is limited and not generally applicable to Tug). The Tug problem involves cryogenics and the established zero-g techniques of using self wicking screens to apply capillary phenomenon which are extremely sensitive to the propensity of cryogens to form bubbles. Design effort in either key area - weightless fluids on heat transfer/fluid phase change - is necessarily dependent on empirical data. However, the validity of combined data is virtually unexplored experimentally and an integrated approach is necessary.

Specific technology gaps involved are listed below.

Heat and Mass Transfer at the Interface. Interfacial heat and mass transfer for a contained cryogenic propellant can have appreciable effect on bulk gas and liquid conditions. The interfacial phenomena relative to the

effects of wall heating will be especially significant for the low heat loads anticipated for the Tug APS tank which is conditioned by a wall-mounted cooling coil.

Flow Phenomena Within and Through Capillary Barrier Materials. The APS auxiliary tank configuration features a capillary barrier screen to form the tank inlet port. Four general classifications of material properties or flow phenomena which must be considered for selection of a suitable capillary barrier material are as follows:

1. Wicking

2. Dewicking or draining

3. Bubble pressure phenomena (passage of vapor or gases through a wetted screen)

4. Flow of propellant through the material

All of the above have one characteristic in common: they depend on the material geometry and the "microscopic" flow of liquid and/or vapor, i.e., the important length scales for the flow processes are wire diameters, and pore and interstitial diameters. To develop any real understanding of the above phenomena, it is necessary to have a physical model of the various flow processes for the capillary material of interest.

Effect of Vibration and Impulsive Maneuvers on Propellant Retention by Capillary Barrier Materials. The performance of capillary devices under impulsive applied and vibrational accelerations has been the subject of a limited number of studies and is not well understood.

Tests have shown that sinusoidal oscillations at low frequencies (10 to 20 Hz) did not affect the bubble pressure or critical Bond number providing the acceleration due to the vibration is added (as a vector) to the Earth's gravitational field. At higher frequencies the bubble pressure capability increased somewhat, but at sinusoidal frequencies between 230 - 280 Hz the screen became destabilized at Bond numbers below the static stability limit. Apparently, destabilization was due to a resonance interaction of the screen and supporting structure with the liquid. For random vibrations, screen stability was predictable from static stability results if the root mean square (RMS) acceleration level was used.

Capillary Collector Vapor Formation. One of the critical technology gaps concerning application of surface tension devices for the acquisition and transfer of cryogenic propellants is that of vapor generation within the capillary collector. Formation of vapor can occur either through heating or by depressurization.

Required Effort

Effort is required to further develop design concepts and conduct experiments to support the technology required for a zero-g APS propellant

acquisition system. Both ground thermal performance tests and in-flight zero-g fluid tests are required at the breadboard or phenomenological simulation level. Flight tests should be on Skylab or other available spacecraft. The effort should include detailed planning of these tests.

Specific analyses and tests needed to resolve the technology gaps cited are as follows:

1. Experimental one-g tests for simulation of the low gravity internal tank thermodynamics for a cryogenic propellant.

2. Experimental tests should be conducted to verify the adequacy of the selected collector concept to remain free of internal vaporization caused by heating or by tank pressure decay. Rates of heating and/or depressurization which cause incipient internal vapor formation need to be determined. The degree and necessity for supplemental conditioning of the collectors could thus be proved or disproved.

3. Pressure losses in flowing across candidate capillary barriers should be characterized over the laminar and turbulent regimes.

4. Experiments are required to characterize the friction factors for flow within the candidate capillary collectors, since tests to date have shown turbulent regime pressure losses to be several-fold greater than calculated using smooth tube correlations.

5. Physical models should be formulated and analytic studies conducted to develop realistic flow models and predictive techniques for bubble pressure, barrier flow loss, wicking, and dewicking.

6. Tests of near-prototype hardware should be conducted to assess the effects of vibration on collector stability.

7. Tests should be conducted to simulate feedout from a partially filled compartment during lateral acceleration to determine if the screen will rewick and prevent backflow.

8. Further testing and evaluation of Robusta screens should be conducted, for if care is taken not to exceed the bubble pressure, these screens provide low flow losses and significant bubble pressure and structural strength. Similar recommendations hold for plain dutch screens.

Expected Results

Empirical data resulting from this research testing will permit valid extrapolation to a prototype design. Heat leaks, chill coil effectiveness, capillary device performance, and zero-g fluid behavior may be confidently predicted from these data.

Timing/Criticality

The research data from this effort is needed in designing the Tug APS propellant feed system and conditioning unit. Therefore, the work should be completed in time to be available for Phase C of Tug program development.

3. Auxiliary Propulsion System Propellant Conditioning System

Problem Statement

The Auxiliary Propulsion System (APS) contemplated for the Space Tug is a gaseous H_2/O_2 integrated system. The system therefore requires a propellant conditioning system to convert the subcritical liquid propellant to a high pressure liquid or gas which is burned in the APS engines, and is also used for fuel cells and main engine start pressurization. Several government funded programs are now being conducted to develop components for a similar but larger size prototype propellant conditioning system originally conceived for the Space Shuttle.

Following is a partial list to indicate the areas of study investigated by various contractors funded by NASA-MSFC and NASA-LeRC which reflects the Shuttle APS but can provide some analytical design data for the Tug. These programs are likely to end in 1972 and some breadboard hardware may be produced. Some verification of the design parameters could be accomplished through this breadboard experimental testing. However, scaling down to the Tug requirements requires verification, particularly in view of the critical dependence upon this equipment for Tug integrated systems operations including the vital attitude control jet system.

Heat Exchangers	- Rocketdyne, Bell Aerospace
Turbopumps	- Rocketdyne
Propellant Conditioning Systems	- AiResearch, TRW, McDonnell Douglas, Aerojet, Rocketdyne
Thrusters	- TRW, Rocketdyne, Bell Aerojet
Igniters	- Rocketdyne
Flow Controllers	- Rocketdyne, Bendix, Parker
Valves	- Rocketdyne, Marquardt

With the subsequent change to a hypergolic system concept, the effort to develop the gaseous H_2/O_2 APS for the Shuttle has been reduced. It is recommended that the current programs should be continued but redirected to reflect the Space Tug APS conditioning system requirements. While these shuttle oriented developments could be reconstituted to support Tug development, the uncertainties are such that the item is assumed to be a Tug-unique item rather than a currently funded item.

Required Effort

The analysis, design, and development of a prototype APS propellant conditioning system for the Space Tug must be performed in order to provide design specification, layout and performance data. This task will include the development of a zero NPSP high pressure LOX and LH_2 turbopump. Problems associated with thermal preconditioning of the cryogenic turbopump must also be solved, and the operating life determined for the hydrogen and oxygen turbopumps.

Items which require further technology development and evaluation include; heat transfer problems associated with heat exchanger icing and subcritical two-phase operation; high-temperature and high-response temperature sensor; and gas generator and thruster mass flow controls. Heat exchanger/gas generator transient and steady state performance data at the high mixture ratio must be generated for nominal and off-nominal operating conditions.

System stability and response analysis of the integrated APS/FC propellant conditioning system is required for the Tug in order to determine the dynamic behavior of the system control loops and component elements.

Expected Results

This effort will produce a prototype propellant conditioning system and parametric design data which can be used to design the components and system in the Tug Phase C study.

Timing/Criticality

The development of parametric design data for the propellant conditioning system is required in order to design a Tug APS. To avoid any possible schedule impacts, propellant conditioning system technology should be sufficiently developed in time to provide adequate design data early in the Tug Phase C study.

4. Electrically Operated Cryogenic Valves

Problem Statement

Electric motor driven actuators for cryogenic valves appear feasible; however, research, design and development are required to evaluate and optimize envelope, weight, output and operational speed characteristics. (Heretofore, cryogenic valves have generally utilized pneumatic actuators.) Further study is also required to evaluate motor operation, torque and speed characteristics, at various temperature levels such as ambient temperature for ground checkout, operation at intermediate temperatures between ambient and cryogenic levels, and also at cryogenic temperatures. Power consumption must also be optimized over this temperature range.

Required Effort

A mechanical design and test program of the motor and associated gear reducer must be made so that clearances at ambient temperature conditions are adequate while insuring that at low or cryogenic temperatures the mating parts such as armature and stator, bearings, and shafts and housing do not seize due to contraction of materials. The judicious review and selection of materials will permit the design of motors and gear reducers that have adequate clearances at low and cryogenic temperatures and yet provide for reliable full power operation at ambient temperature. The detail design of the gear reducer, epicyclic, spur-to-spur, worm, or combination thereof, will be dependent upon the load to be transmitted, speed of actuation and life cycle requirements.

There are many standard fractional horsepower motors currently on the market today. A research program, computerized if practicable, must be developed to evaluate an optimized motor in terms of speed, torque, diameter, length, weight and power consumption which in turn could be compared against existing motors. This data would provide the baseline for the motor design. Selection of motors by this technique will reduce considerably the cost and lead time for engineering development test units.

Expected Results

The study and test program will result in valve actuation motors and gear reduction mechanisms capable of opening, closing, and latching cryogenic propellant valves under both simulated temperature and vehicle usage conditions. Formulated designs will establish some of the more critical design parameters for motor operated valves and will help bring the technology up to that currently in use for pneumatically operated cryogenic valves. Establishment of some of these more critical parameters will assist in determining future design/development test plans as well as valve acceptance test and checkout procedures.

Timing/Criticality

Establishment of critical design parameters for motor operated cryogenic propellant valves is considered essential to the Tug program in terms of defining propellant system design, valve actuation systems, valve timing, component installation, system weight and electrical power consumption. Consequently the design and test program should be completed prior to the completion of the Phase B study so as to establish the feasibility of the approach and determine future design/development programs and costs required for program planning.

3.2.3 AVIONICS

The items identified for supporting research and technology development in the avionics area are:

1. Computer Software Definition

2. Laser Rendezvous Radar System Requirements

3. Rendezvous and Docking Simulation

4. Computer Technology for Reliability and Redundancy Optimization

It is assumed that existing development studies of the laser rendezvous radar at IT&T and the advanced fuel cells at Pratt & Whitney will be continued on separate funding; therefore, costs and schedules for them should be available to NASA internally and are not included in this plan.

1. Computer Software Definition

Problem Statement

The weight, power and cost of on-board computer equipment are primarily affected by software requirements. These requirements are much more complex than those of currently developed flight vehicles, as they include a centralized system to conduct autonomous mission control and on-board checkout. Descriptive estimates of the software therefore cannot be reliably based on historical data indicators.

Accurate software descriptions are needed early in the Tug development as a source for requirements of other functions. All Tug subsystems will be checked out during flight by the on-board computer. The number and description of tests stem from software definition and must be included in component specifications for all Tug subsystems. The ground facility which develops the software needs early requirements for its timely development. Mission control station design, and especially the remote pilot interface, requires descriptions of on-board software to progress efficiently.

Since on-board software requirements affect many long-lead time developments, it is important to initiate definition studies early.

Study Objective

To establish detailed Tug on-board computer software operational requirements.

Required Effort

A three-phase study approach is recommended. The first phase establishes the requirements for on-board checkout of subsystems during flight. Component and subsystem operating descriptions and specifications, which were generated during the Point Design Tug study, will serve as a basis for the requirements. Each test description shall include requirements for added specialized checkout sensors, stimuli command and response format, tolerance limit data, and duty cycle. The requirements will be organized and integrated to specify test sequences and schedules which will form the basis for checkout program and table storage development.

In the second phase the software operational program arrangement will be developed. Preliminary logic will be described for each anticipated program, including the following functions:

Executive

On-board Checkout and Diagnostics

Guidance and Navigation

Flight Control and Stabilization

Main and Auxiliary Propulsion Operation

Navigation Sensor Management

Propellant Management and Conditioning

Communications Management

Electrical Power Management

Environmental Control

Tables required for each of the programs will be defined and sized. Program operation will be described in sufficient detail to yield preliminary word count estimates.

The third phase of the study will be devoted to an assessment of software operating timelines and the requirements for computing speed, memory capacity and data bus pulse rates.

Expected Results/Outputs

The study will result in preliminary software definition to the extent necessary to specify the on-board computer hardware, test sensors in all other on-board components, vehicle status downlink and command uplink formats, and preliminary requirements for both the ground control station and software development facility.

Timing/Criticality

The results of the study serve as a basis for main elements of Phase B design which strongly influence vehicle weight and cost, as well as ground facility features. For this reason the study should be completed before the beginning of Tug Phase B development.

2. Laser Rendezvous Radar System Requirements

Problem Statement

Unmanned rendezvous and docking has not been accomplished by this country to date. Several studies investigated the rendezvous approach and final docking philosophies, which include many of the most demanding aspects of rendezvous and docking operations. A study which encompasses the systems design and operation of a laser system, considering all phases of rendezvous and docking, needs to be conducted.

The laser configuration and capability influences the requirements of many other subsystems and components, and imposes requirements on the target and the ground control facility. Although many of the questions concerning laser configuration and capability can only be answered by simulation, a separate study of operations and interface descriptions should first be conducted. Many of these operations were never analyzed; for example, target acquisition by the laser prior to target orbit circularization, as opposed to acquisition after circularization, may produce significant propellant savings and may increase the probability of mission success. Acquisition of the target from an arbitrary angle now appears to be a necessity, but little is known of the optimum strategy to circle the target for docking port alignment.

An immediate study to investigate these, and many other new aspects of rendezvous and docking, would permit Phase B Tug development studies to use realistic requirements in this area. Furthermore, greater definition of ground control station and payload interface requirements would be available for parallel studies.

Study Objective

To synthesize and establish requirements for the laser rendezvous and docking radar to be utilized in the hardware development program in support of TUG.

Required Effort

Mission requirements and spacecraft characteristics will be obtained from recent Tug and Orbit-to-Orbit Shuttle studies. Rendezvous acquisition timelines will be established parametric with range, and position uncertainty, and time-competitive events such as circularization burn time and guidance computation time. Comparisons of propellant usage based on pre- and post circularization acquisition will be made. The probability of target acquisition as a function of position and velocity uncertainties will be assessed. Maneuvers necessary for docking port alignment will be described in terms of propellant usage and timelines. Requirements for laser design to facilitate rendezvous and docking will be defined in conjunction with potential supplier recommendations. Preliminary rendezvous and docking subsystem interfaces will be described. Requirements for target reflector locations and remote pilot displays will be formulated.

Expected Results/Outputs

The results of the study will include a description of the laser rendezvous and docking subsystem design requirements to the component level, an operational timeline, APS propellant requirements, and subsystem interface requirements. The description will provide a basis for future man-in-the-loop simulation of rendezvous and docking operations.

Timing/Criticality

This study is needed prior to Tug Phase B design, since it affects operations, spacecraft performance, and design.

3. Rendezvous and Docking Simulation

Problem Statement

The Tug vehicle in its associated missions will employ the use of several new baseline and some alternative concepts which represent new spacecraft technologies and operations. Paramount among these are:

- Remotely controlled man-in-the-loop docking and vehicle inspection using television and laser radar cues.
- Automatic rendezvous and docking using laser radar.
- Remotely controlled man-in-the-loop acquisition and rendezvous using television systems.

Some independent studies such as RMU, Shuttle attached manipulator, automatic laser docking, etc., have been conducted relating to these concepts; however, it is necessary to integrate these results, and resolve new problems unique to the Tug before the feasibility of the application of these concepts can be fully established. The development of a hybrid simulation system capable of supporting both the phase B and pre-phase B study efforts associated with the rendezvous, docking, and inspection mission phases is considered essential to the success of the TUG program. This simulator will provide a realistic but economical proving ground for the evaluation of concepts, the establishment of basic system configurations and requirements, and will help avoid the necessity of major changes later in the Tug development. The simulator must be capable of supporting the following critical research, technology and development problem areas which require satisfactory resolution prior to the phase C design effort:

1. Docking and Vehicle Inspection

   I. Vehicle and Subsystem Configuration Determination and Evaluation

      a. Control system selection and evaluation.

      b. Definition and evaluation of controls and displays, including possible use of graphics.

c. Television and illumination system requirements, such as acceptable frame rates and docking and inspection light configurations.

d. Evaluation of engine and sensor configurations, and establishment of requirements.

e. Determination of acceptable command and data rates.

II. Statistical Determination of Payload Docking Accuracies

a. Determination and evaluation of acceptable visual docking aids.

b. Determination of attainable docking accuracies and final state vectors necessary to establish the baseline configuration and design of the docking interface.

c. Determination of mission timelines.

d. Determination of propellant and electrical power system requirements.

III. Laser Radar System Evaluation

a. Evaluation of a laser controlled automatic docking from random initial target vehicle orientations.

b. Evaluation of the laser radar as an active element of the control loop.

c. Determine radar relative attitude and docking display configurations and acceptable data rates.

IV. Contingency Docking Investigations

a. Television-only docking.

b. Off-nominal docking conditions such as slowly moving target and degraded television image due to transmission loss and noise.

c. Engine failure effects on vehicle performance.

2. Visual Acquisition and Rendezvous

I. Establish the theoretical visual acquisition range as a function of approach angle, sun angle and target vehicle orientation using the target vehicle configuration and reflectance characteristics.

II. Verify the visual acquisition range by superimposing a point source on the simulator's star field background.

Study Objectives

Develop and check out a flexible SPACE TUG Simulator capable of supporting the rendezvous, docking and inspection mission phases. Obtain preliminary resolution of baseline problem areas and support other research and technology efforts.

Required Efforts

Determine the simulator requirements. Review previous similar activities to determine their applicability. Develop mathematical models for the mission environment, vehicle dynamics, and required on-board and ground based systems.

These models are to include necessary transmission lags and communications equipment characteristics. Convert the mathematical models to analog mechanizations and digital software. Develop a flexible control station using control and display requirements defined by previous studies as a starting base. Flexibility in the design of the control station is necessary to allow for the incorporation of new control and display requirements as well as modification of existing configurations. Develop the necessary physical scale models of the target vehicle. Design and develop the required interface equipment to permit the integration of a breadboard laser radar system into the simulation. Modify and update existing visual display equipment to provide the required television and laser radar scenes. Integrate and checkout the simulation complex. Operate the complex as required to support research and technology and development study efforts. The technology and equipment required to develop a simulator of this nature is state-of-the-art. An illustration of the simulator is contained in Figure 3.2-1. Use of an existing simulation facility such as at MSFC, LRC, MSC, NR, etc is assumed.

Expected Results/Outputs

This effort will produce a study tool in the form of an operational simulator which can be used initially to establish system feasibility, and support the development of the various TUG concepts and baseline systems associated with the rendezvous, docking and inspection mission phases. This system will become the baseline simulator which may be updated and expanded to support future detailed design, mission evaluation, procedures definition and training.

In addition, using the mission descriptions and system requirements established by previous studies as a basis, the critical problem areas outlined in the problem statement will be investigated. A number of these problem areas are defined either directly or indirectly as separate research and technology efforts; this does not indicate duplication of effort but rather illustrates the requirement for early simulator support.

Timing/Criticality

The simulator development should begin as soon as possible in order to insure its operational status when required to support pre-phase B and phase B efforts.

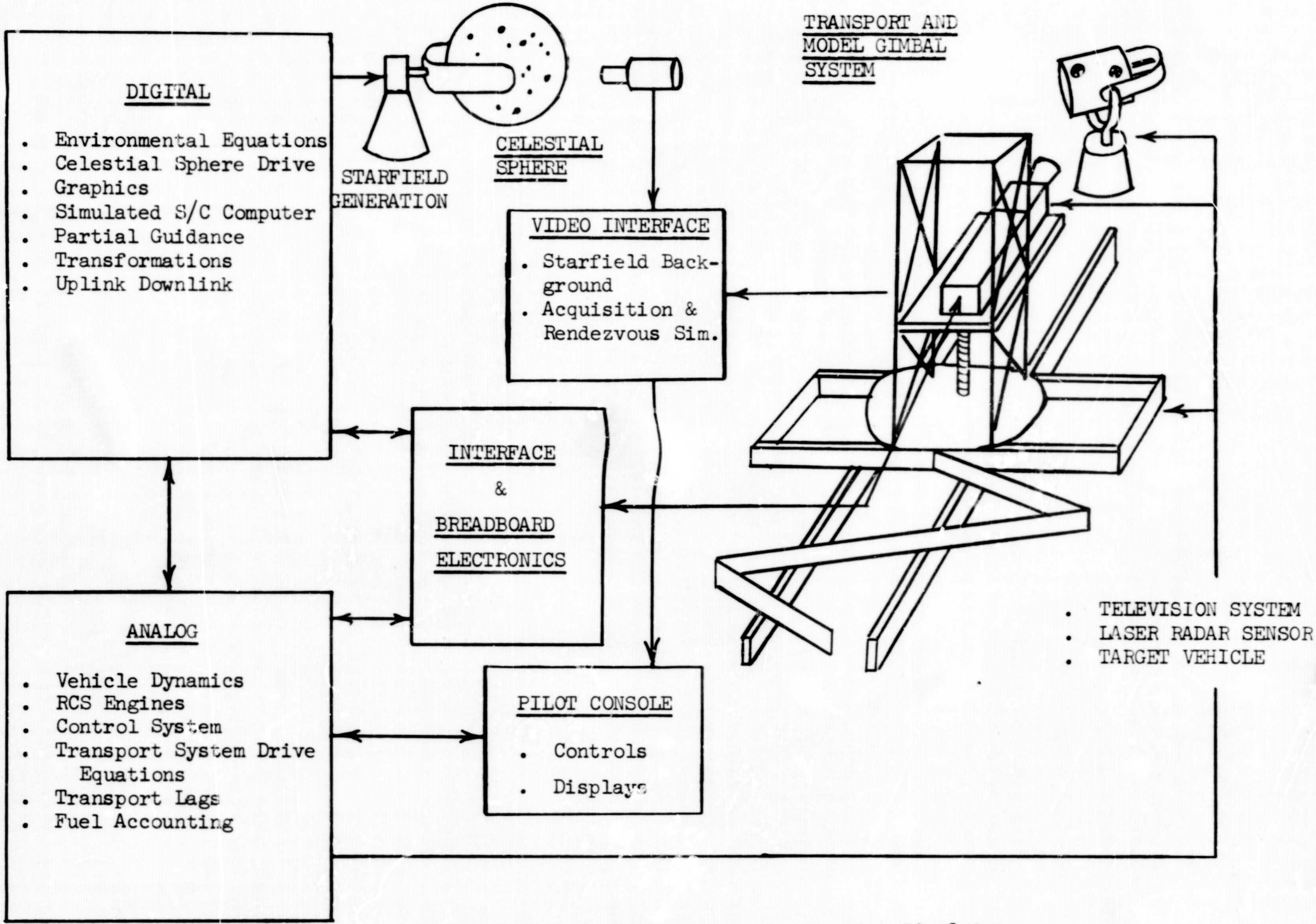

Figure 3.2-1 Tug Rendezvous and Docking Simulator

4. Computer Technology for Reliability and Redundancy Optimization

Problem Statement

The multiple inter-relationships among the many Tug components are too complex for reliability to be computed effectively by hand. Each function must be examined for design margin, redundancy, and maintainability and related through success logic to achieve mission success within constraints of low weight and low cost. A large amount of reliability analysis would be necessary to consider each success mode for each function and to evaluate their relative magnitudes.

In the past, successive approximations and arbitrary rules were utilized to approach an optimum configuration. Initial estimates for the success means of redundancy, design margin, and maintainability were based on experience with similar vehicles. Weight and cost values were then determined for the specific configuration. Revisions of the values for the success means were made in the direction of lower weight or cost. This procedure was repeated until a feasible configuration was found to represent the best combination of means that had been analyzed. The result was only as good as the analysts experience and optimum only by chance. Arbitrary redundancy rules for the initial configuration neglected experience and was fraught with judicious exceptions.

The Tug program will require very careful evaluation because of the impact of reliability on cost and weight. An early attempt at optimization showed a very narrow range of minimum cost against reliability: high reliability requires excessive development cost and low reliability results in excessive replacement costs. Small changes in resulting actual reliability could increase cost appreciably.

Required Effort

Advanced mathematical techniques must be applied to the definition of system reliability requirements for the Tug in order that all factors can be incorporated in a quantitative synthesis of an optimum configuration. Initially, reliability logic and mathematical models of a simplified Tug mission will be developed for the significant criteria of cost and weight. These mathematical models will be designed to apply to optimization by Geometric Programming. Typical numerical values for parametric constants will be utilized in the equations for determining an optimum mix of functional and subsystem reliability as obtained by design margin, redundancy, and maintainability. Sensitivity of criteria and reliability mix to parametric constants will be investigated by iterative application of the optimization program.

The study can produce significant results within a period of three months. Overlap between the reliability analyst and the computer specialist is required to provide mathematical model modification for computer application and direction of changes to parametric constants toward realistic configurations.

Expected Results

A methodology will be developed for optimizing system, subsystem, and component reliability through computer methods. The multiplicity of variables involved in on-board design margin and redundancy as well as on-the-ground component replacement will be capable of being considered in an orderly, logical fashion. Direct application to the Tug vehicle will be possible through the preparation of system success mathematical models in the format of "Geometric Programming" and the calculation of optimum design margins and redundancies. The results can be used to determine the next level of detail as the program proceeds as well as to later evaluate the particular configurations proposed as a consequence of additional design constraints not specifically considered in the optimization. Further, as the Tug study, hardware fabrication, and operation is accomplished, rapid re-evaluation of the optimums will identify weaknesses and strengths in the configuration; re-direction for emphasis on low reliability and de-emphasis for high reliability.

Timing/Criticality

The development of reliability optimization methodology is critical to the Tug study for inexpensive consideration of all significant variables in determining initial, interim, and final configurations. Consequently, the research should be accomplished prior to the completion of the Phase B study in order for all proposed designs to reflect the best combination of reliability means toward the mission objectives. A system evaluation tool will be developed which can direct the development of redundancy requirements.

3.2.4 TUG/EOS INTEGRATION AND MISSION ANALYSIS

In this area, two items were identified for SR&T. Payload studies indicate the Tug as a third stage will be one of the major Shuttle "payloads," being present on as many as 2/3 of the Shuttle missions. A continuing low level effort is needed to assure all EOS/Tug interfaces minimize the weight impact on the Tug.

Further effort in mission analysis could improve the calculated payload delivery capability and could be extremely cost effective in terms of increased payload or a lower permissible mass fraction. Three separate mission analysis sub-tasks are prepared.

The items identified are:

1. Tug/EOS Interfaces
2. Mission Analysis — Tug Performance Optimization
   (a) Multi-orbit injection with optimal Tug thrust level
   (b) Optimal altitude for Tug release
   (c) Dual Shuttle launches for Tug deployment and retrieval

1. Tug/EOS Interfaces

Background

Several different Tug operational configurations and staging modes have been studied in the past two years. The resulting gross weights and dimensions varied widely. Meanwhile, the Earth Orbital Shuttle cargo bay geometry and the Tug configuration have been the subject of considerable study in the past year. In this period the concept for the EOS Orbiter has varied substantially, making it impossible to perform a specific detailed integration of any given Tug design with "the Orbiter" as might otherwise be expected in a 3-stage Space Transportation System.

From the EOS point of view, the Orbiter must also accommodate other "payloads" in addition to Tug; such items as sortie modules, experiment modules, tankers, SOAR, station modules, etc. While the Tug appears to be the primary payload for the Orbiter, these other payloads must obviously be considered also and a common set of payload accommodation provisions furnished, if possible. Of all the likely Orbiter payloads, the Tug as the high performance third stage of the Space Transportation System is undoubtedly the most frequently used and is also the most intolerant to scar weight for installation provisions. Therefore, it is logical to presume that the requirements for Tug should predominate in the considerations for payload accommodation in the Orbiter. Because of the criticality of inert weight in the Tug concepts, the current designs reflect approaches for Orbiter installation which provide attach points, umbilicals, and structural supports distribute loads into the Tug with minimum Tug weight impact while maintaining reasonable compatibility with a typical Orbiter design. The latter considerations include compatibility with the cargo bay basic structure and load paths, influence on Orbiter c.g. position, fluid and electrical umbilicals and line routings, and compatibility with the Orbiter deployment/retrieval manipulator concepts.

Required Effort

It will be necessary to maintain a continuing effort in the definition of Tug/EOS interface provisions and operations as both elements of the Space Transportation System are further defined. This will insure the proper balance and compromises as well as overall system optimization between these elements to insure total system performance adequacy and feasibility. This effort is particularly important due to the sensitivity of the Tug concept to inert weight and to the rapidly changing evolution of the Orbiter concept.

Particularly required will be the optimization and definition of the structural support interface, the fluid and electrical umbilicals (disconnect and re-connect), the deployment and retrieval concept, and the docking/latching mechanism approach. Structural support studies will need to consider the minimum impact on Tug inert weight consistent with reasonable Orbiter cargo bay structural compatibility and adaptability for alternate Orbiter payloads. In establishing umbilical requirements, minimum Tug weight, routing of lines, and integration with interfacing Orbiter systems must be considered. Umbilical alignment and re-sealing will be an added requirement for these remateable disconnect umbilicals. Utilization of and compatibility with the

deployment/retrieval concept of the Orbiter is essential and is related as well with the docking/latching concept. Use of manipulator arms can eliminate need for "hard docking," for example. The retrieval/deployment mechanism, such as a hinged base support ring, can also be an integral part of the structural support. These considerations will need continuous attention during the early development phases for the Space Transportation System to assure the optimum set of compromises without undue penalty to one element and to achievement of necessary end item performance.

Study of Tug interfaces should proceed along with EOS definition studies and should be continued into EOS Phase C studies.

Expected Results

Continuous study of the Tug/EOS interfaces insures that the optimum set of compromises will be made. The study will be conducted in conjunction with related EOS study effort. This will impose the minimum structural weight penalty on Tug for the physical support interactions and for the umbilicals and deployment/retrieval concepts. The study will help determine the optimum orientation of the Tug within the cargo bay, the method of adapting to strong points along optimum load paths, compatibility with the provisions for removing and re-inserting the Tug as well as the manner in which it is docked or attached to the Orbiter, released, and reattached. The interface support provisions may also be utilized wholly or partially during ground operations as GSE handling fixtures.

Timing/Criticality

This study should be a continuous effort throughout the Space Transportation Studies. However, a low level effort should be started immediately so the study results can be factored into both Tug and the EOS study for consideration in current and forthcoming study phases.

2. <u>Mission Analysis — Tug Performance Optimization</u>

Problem Statement

The extreme emphasis on a low inert weight for the Tug allows the vehicle to fly the rather demanding current baseline mission but the final result may be a Tug that is unnecessarily costly. An alternate approach is to enhance the Tug's performance capabilities by <u>indirect</u> means rather than putting all the emphasis on obtaining a very high mass fraction. Specifically, the following approaches may yield highly beneficial performance improvements at a relatively low cost:

1) Use multiorbit injection technique coupled with the corresponding optimal Tug thrust level.

2) Select the optimal altitude for the Shuttle to release the Tug. Coupled with this effort would be the determination of the best Tug phasing orbit when it comes back from the payload delivery.

3) A systematic study of gross changes in the mission philosophy. In particular the practicality of deploying the Tug with one shuttle and retrieving it with another having a larger propellant load.

Required Effort

The study will be performed in three parts with specific subtasks as follows:

1. Multiorbit injection/thrust level optimization

   a. Simplify an existing multiorbit computer program to obtain more efficient simulation characteristics.

   b. Introduce capabilities for cutoff on apogee altitude rather than orbital energy and alter the program to provide the subsequent circularization V as a function of the final transfer conic.

   c. Incorporate the stage thrust scaling laws and have the program automatically sweep through a fan of thrust levels.

   d. For a cross section of Tug missions, determine the optimal thrust level/multiorbit injection combination.

2. Optimal selection of the tug release and phasing orbits

   a. Collect a definitive set of performance capabilities for the current Shuttle vehicle.

   b. Determine the optimal circular release orbit considering Shuttle performance loss with increasing altitude, the corresponding Tug performance gain, and the change in shuttle orbit maintenance propellants.

   c. Conduct a similar set of optimal tradeoffs for elliptical release altitudes.

   d. For each case above, determine the best available return phasing orbit considering all attendant geometry and performance problems.

3. Dual Shuttle launches for Tug deployment and retrieval

   a. Compile baseline data on the launch frequency and payload limitations as a function of mass fraction and Shuttle performance capability.

   b. Determine the allowable mass fraction reduction that results from flying a second Shuttle for the pickup of the Tug in a higher orbit.

   c. Examine attendant Shuttle problems including Shuttle reenetry at a higher than normal velocity.

Expected Results

The schemes under consideration can increase the Tug allowable burnout weight by 500 to 1000 pounds. This will allow the designers to use cheaper, heavier components and will provide for extra redundancy. Such a performance gain may also allow the elimination of some expensive subsystems such as a propellant utilization system or a throttleable engine.

The resultant simplification in design could appreciably reduce the cost of the Tug.

From an alternate viewpoint if it is decided to pursue a highly efficient Tug design, the performance enhancement could permit higher payload capability. The resulting gain of 500 to 1000 pounds per mission would permit increased mission growth and flexibility.

Timing/Criticality

Evaluation of the performance enhancement schemes should be completed as soon as possible since this may result in a lower permissible mass fraction.

3.3 BASELINE POINT DESIGN SR&T SCHEDULE AND EXPENDITURES

The timing requirements for the Tug-unique supporting research and technology items previously identified are shown in Figure 3.3-1. The Tug Phasing Schedule is shown on the top of the chart assuming a NASA Phase A go-ahead of early 1972. The SR&T items are correlated directly with this Phasing Schedule. Most of the SR&T items are accomplished concurrently with Phases A and B so the information obtained will be available for use as required in Phases B and C. While activity on each task could continue beyond that shown, the ends of the activity bars are determined by the need for the results of these research efforts within the main program development phases. After subsystem characteristics are established, development can continue under either the main program Phases C and D or by extended separate funding.

Figure 3.3-2 shows the yearly expenditures for this SR&T. Most of the expenditure is in the areas of Structures, Materials and Dynamics and in Propulsion. The yearly expenditures are as follows:

1972	$1.415M
1973	3.865M
1974	3.030M
1975	.560M

Again, these items do not include the costs for the currently funded research items such as high P_0 engines, APS, advanced fuel cell, laser radar.

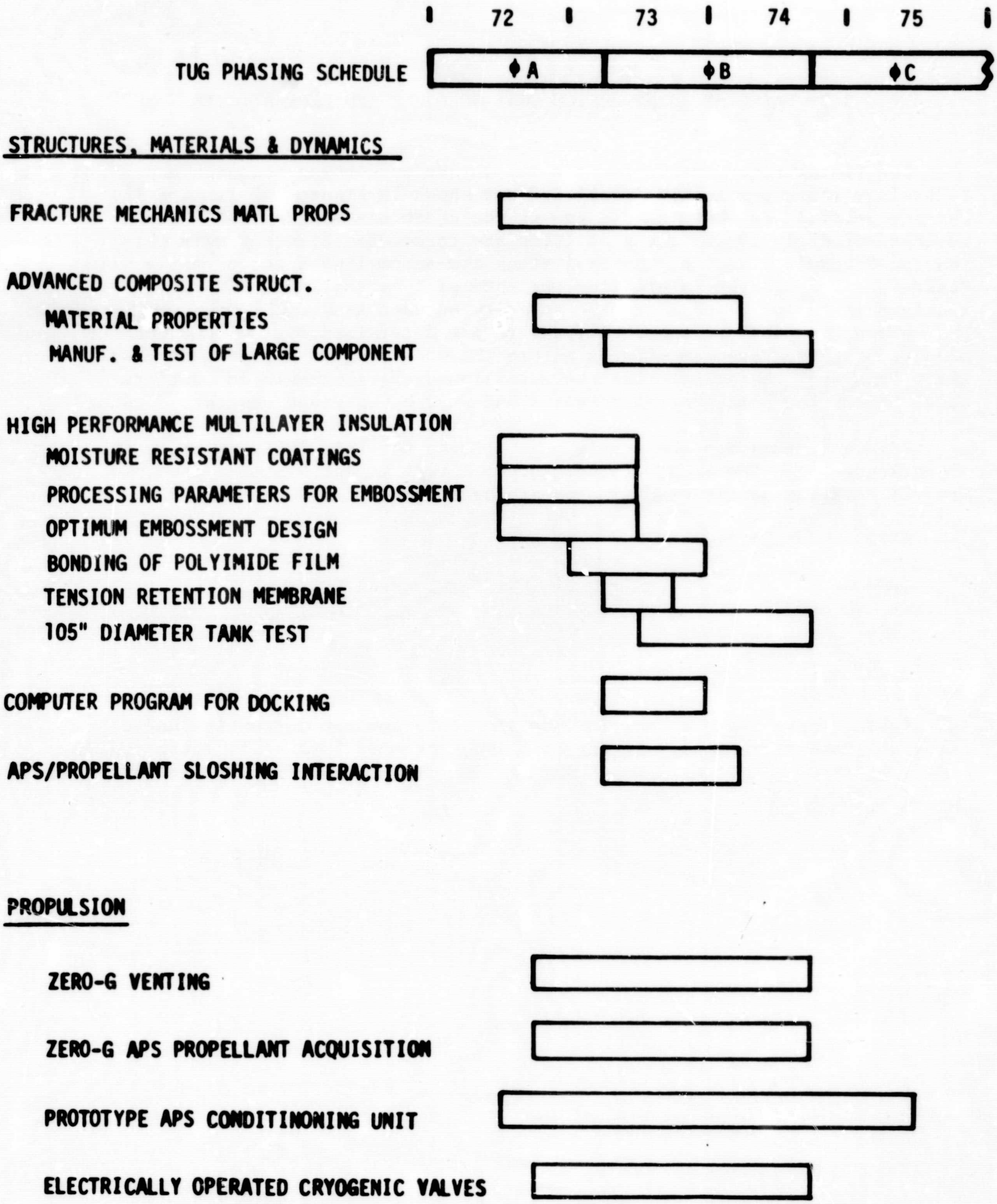

Figure 3.3-1 SR&T Schedule

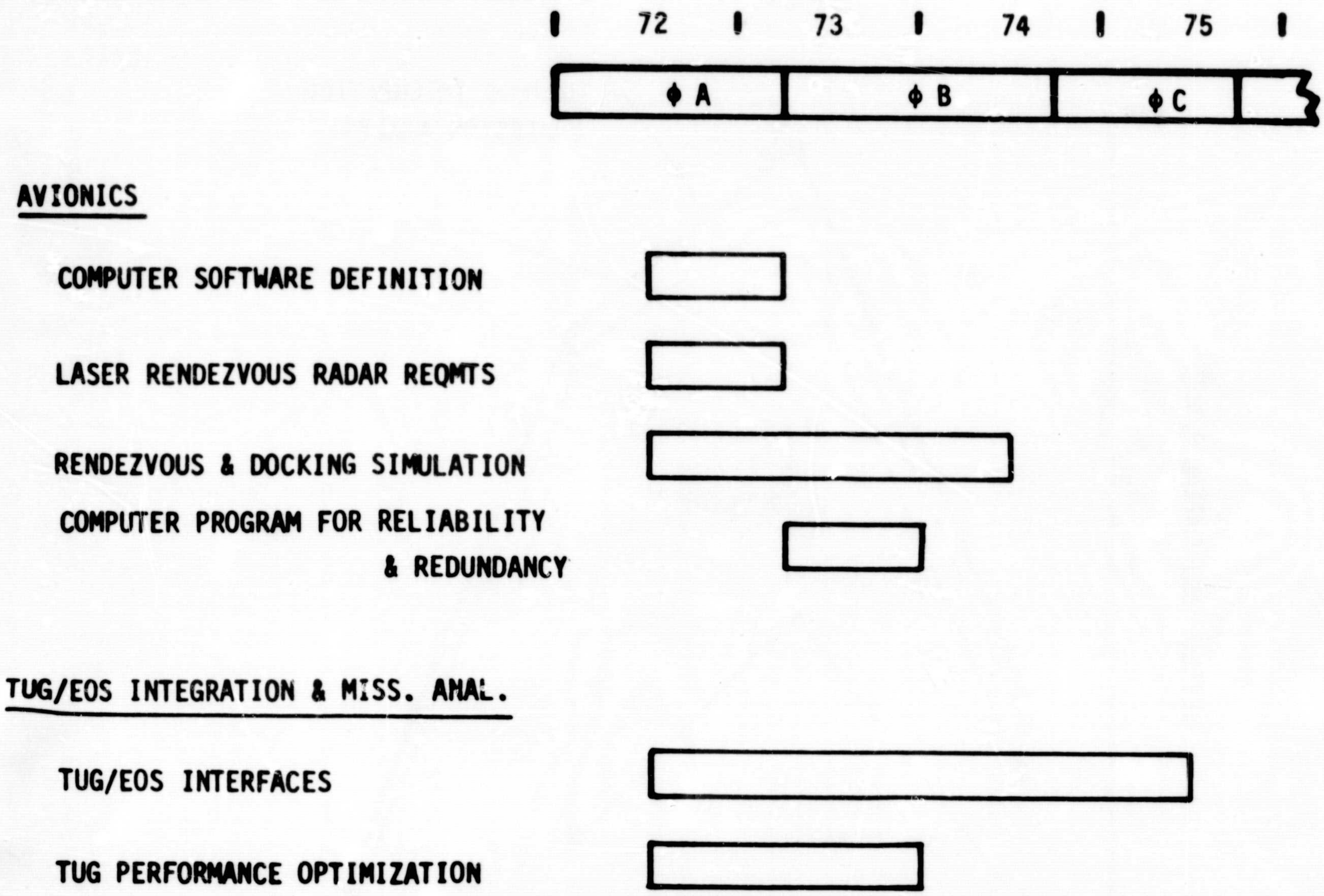

Figure 3.3-1 SR&T Schedule (Cont.)

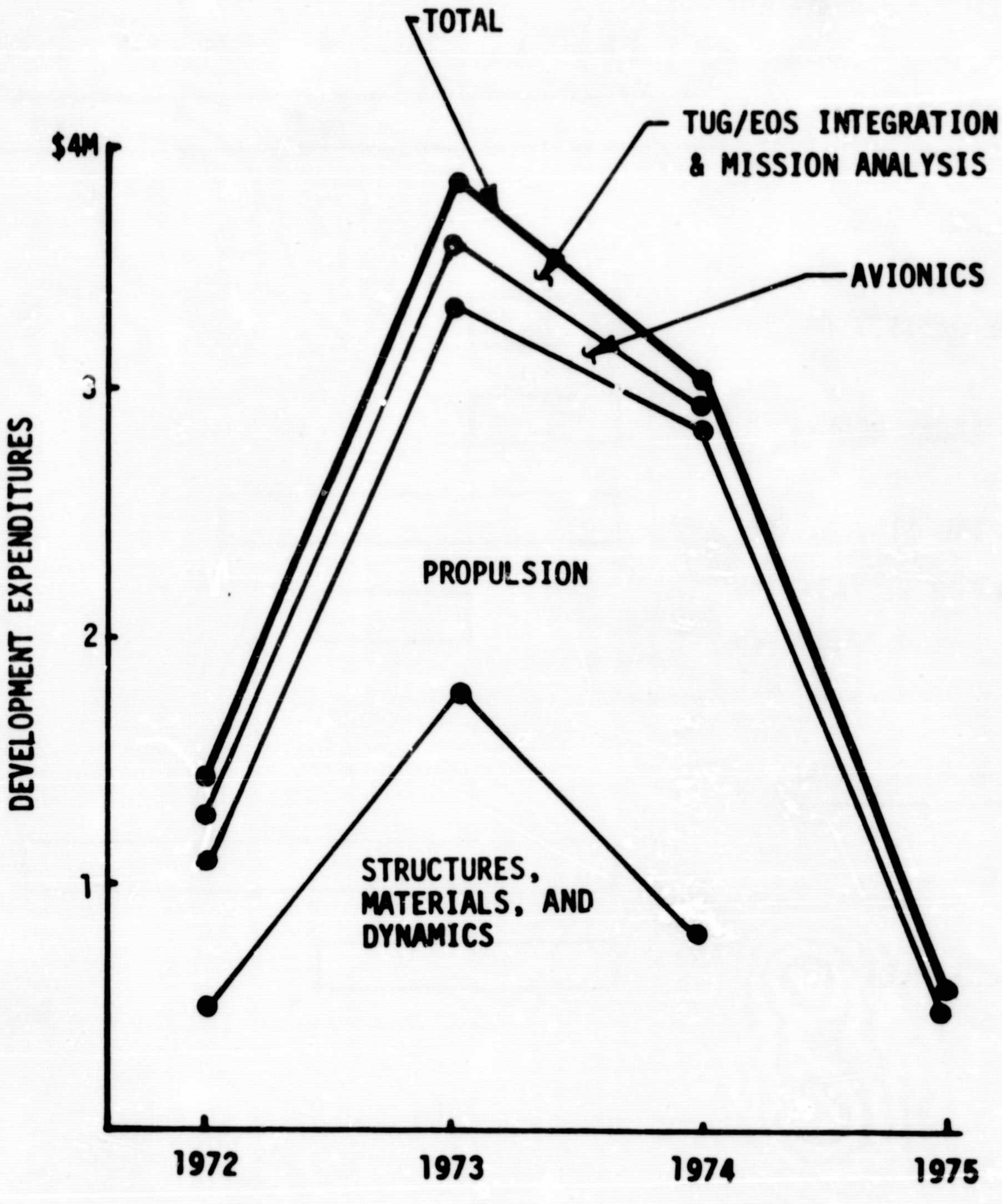

Figure 3.3-2 SR&T Development Expenditures

(Does not include current SR&T programs such as Advanced Engine Development, Lasar Radar, Advanced Fuel Cells, and GO_2/GH_2 APS Engines)

3.4 NORMAL PROGRAM PHASE TIME-CRITICAL AVIONICS TOPICS

The following items are not separate SR&T items but are normal Phase A-B activities that deserve special attention or flagging.

3.4.1 COMPUTER-SUBSYSTEM INTERFACE STUDY (PHASE B)

The buffer equipment which converts computer commands to a form which can be used by other subsystems, and converts sensory data to computer format, comprises a significant part of the data management equipment. Weight and power requirements of the buffer equipment cannot be accurately estimated until detailed signal conditioning and voltage level requirements, based on the needs of all other subsystems, have been established.

The requirements for all electrical sensors and controls used in the Tug should be tabulated. These requirements form the basis for the buffer equipment design. The design can incorporate features of similar units built for the B-1 aircraft, but will be arranged so that new functions can be easily added. Weight, power, and cost estimates should be derived for the design.

The study output will consist of buffer equipment signal conversion requirements and a preliminary design which includes estimates of weight, volume and power consumption.

3.4.2 COMMUNICATION SUBSYSTEM, S-BAND ANTENNA PATTERN STUDY (PHASE B)

The flush-mounted S-band antennas proposed for the Tug communications subsystem provide omni-directional pattern coverage to insure reliable communications with all external interfaces (EOS, MSFN, DSN). The attainment of an omni-directional, or null-free, radiation pattern is virtually impossible, assuming an antenna system reasonable in cost and complexity.

A scaled-down model of Tug and antenna systems should be constructed and tested at an antenna range.

This study will provide actual antenna radiation and receiving patterns required to substantiate signal margin calculations. The study output will consist of empirical data to support theoretical calculations and insure and optimum antenna location.

3.4.3 AUTONOMOUS GUIDANCE AND NAVIGATION PARAMETRIC STUDY (Part of Normal Phase B Study Effort)

Injection errors at the rendezvous interface are inherent in autonomous guidance and navigation of a transfer for spacecraft from one circular orbit to another. The magnitude of the injection errors, whether a requirement or

a capability, directly involves other flight system functions and equipment, such as rendezvous requirements and operational characteristics, the selection of guidance and navigation subsystem mechanization, and the definition of guidance and navigation software requirements, computational requirements, and functional requirements. Influence coefficients must be generated to quantitatively relate mission and system parameters.

Parametric Analysis data must be generated to consider the following factors that influence injection errors:

System error sources including initial state errors, initial altitude/attitude alignment, gyro errors, accelerometer errors, star tracker errors, horizon tracker errors, and navigation sensor alignment uncertainties; sighting schedule including measurement types and measurement frequencies; navigation software including environment model, state estimation algorithm, observational data smoothing, and bias estimation algorithms.

This effort should provide:

1. Rendezvous Interface Conditions - position error volume at the rendezvous interface for Tug missions.

2. State Error Propagation - guidance and navigation system performance as a function of time, mission operations, and combinations of sensor instruments.

3. Midcourse Correction Budgeting - estimates of midcourse ΔV maneuvers related to sensor errors and state vector update scheduling.

4. Software Estimates - computational requirements for specific subsets of guidance and navigation data processing operations.

3.5 FURTHER ADVANCED AND ALTERNATE TECHNOLOGY (NON-BASELINE)

3.5.1 SUMMARY

This section deals briefly with two additional areas of supporting research and technology. The first of these concerns technologies which are advanced beyond the 1976 level. The second area concerns technologies which could be utilized in place of those used for the Baseline Point Design (as covered earlier). The reasons for utilizing such alternative technologies are varied but may be further sub-categorized as those which could possibly improve payload performance even further and those which provide other benefits (i.e., cost, reliability), quite often at a performance penalty. The items of alternate technology utilization are identified in Figure 3.5-1. Additional study in the immediate future should be undertaken for these latter option items so that they are considered to the same degree and depth as the baseline items in preparation for succeeding study phases.

Post-1976 Items

Further experience with advanced engines should be reasonably expected to yield additional performance improvement but no more than 1 percent I_{SP} increase can be foreseen. Slight weight reduction is likely as well as potentially lower allowable pump inlet pressure values.

Multi-layer insulation (MLI) materials and design improvements should enable design of systems able to withstand corrosion so that the purging requirement can be eliminated.

Improvements in electrical power distribution equipment such as connectors, switches, relays, terminals should result in some further weight reduction.

Further experience with manufacturing and utilizing advanced composite materials could possibly lead to increased material properties predictability such that design allowable stresses could be further increased. This increase in allowable stress could permit a reduction in material thickness and a corresponding reduction in Tug inert weight.

In Avionics, some general decrease in electronic components weights should also be expected with time. A new horizon sensor design which does not require deployment for adequate field of view could simplify vehicle design. A small separate dedicated guidance and navigation computer would simplify software and thus save costs.

Alternates to Baseline Technologies

The other class of possible desirable technology items are those which could be considered alternates to those chosen for the baseline design.

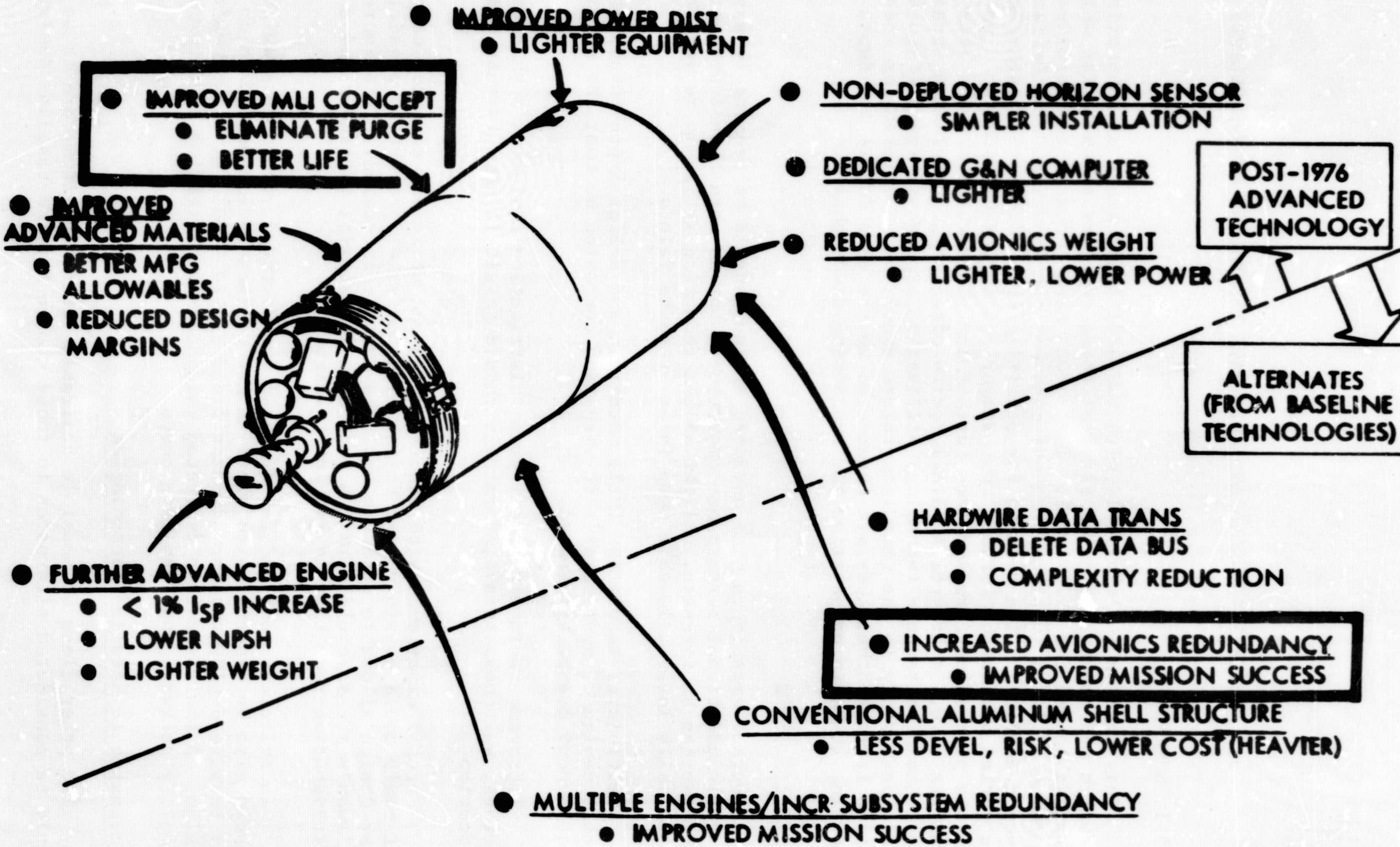

Figure 3.5-1 Possible Advanced/Alternate Technologies

Increased engine subsystem redundancy or even two engines might be preferable to one in order to provide additional redundancy for mission success improvement, albeit at a penalty in weight. Use of more conventional aluminum honeycomb shell construction could reduce development risk and cost but at substantial weight penalty.

In Avionics, the option to increase component redundancy could improve mission success probability, although at a weight penalty. In this small vehicle, use of dedicated hardwire data transmission rather than data bus could reduce complexity and software.

3.5.2 DISCUSSION - FURTHER ADVANCED MECHANICAL SYSTEMS TECHNOLOGY (1976-1985 Time Period)

Advanced Engines

Based upon work accomplished in the USAF/SAMSO Orbit to Orbit Shuttle study, it is believed that a small increase in engine specific impulse over the 1976 values used in the Baseline study could be expected with further development in the following decade. The maximum improvement potential of up to 1% would require extensive turbopump redevelopment (i.e., hydrodynamic bearings) and higher chamber pressure/area ratio ; an increase of 1 second in specific impulse would appear more likely. At the same time, progress in the state-of-the-art in this period should permit modest improvements in engine turbomachinery such that some reduction of inlet NPSH requirements might be achievable. This would permit a reduction of required vehicle tank pressure (or allow more feedline loss) to enable a net weight saving. A reduction in the current (1976) required pump inlet pressure (NPSH) values of 2 ft LOX/16 ft LH_2 could be reasonably expected, as low as 1 ft and 8 ft, respectively.

Weight reduction predictions are most difficult to make so far in advance but some minor engine reduction might be conceivable as a result of component design refinement or materials fabrication change.

Further Improved Multi-Layer Insulation Concept

Within the decade following 1976, it appears reasonable to expect that further research and experience with MLI materials fabrication and application should result in an overall still further improved concept. For example, the use of different metallic coatings (i.e., gold, nickel, etc.) on inert substrates may result in a concept which is not sensitive to atmospheric contaminants. A sealed, evacuated approach might also become feasible. In general, these could alleviate or eliminate the present requirement for excluding air or inert gas purging on the ground and in atmospheric flight, and should result in a more rugged and less pressure-sensitive MLI installation leading to easier installation, maintenance, and repair. While considerable research has been conducted on MLI concepts, particularly for blankets of aluminized Mylar, this is considered a fruitful area for much further work even beyond 1976 to improve physical characteristics, performance predictability, and service life.

Improved Advanced Materials

It is reasonable to assume that in the post-1976 time period a further improvement in composite materials properties and manufacturing fabrication techniques could result in higher allowable stresses and more uniform/ predictable performance. These gains might allow moderate reductions in design margins and permit structural weight reduction as compared to the values currently estimated for 1976, although the latter are already quite advanced.

Improved Power Distribution

In keeping with the general trend in Avionics toward miniaturization and reduced power consumption it is believed that in the post-1976 decade some further weight/volume reductions should be realized. Electrical distribution equipment such as power control and transfer switches, connectors, terminals, disconnects and conductors are examples of possible improved items that should be a fallout of general activity in advanced electrical power and distribution systems. It is also possible that further weight-saving integration of power and signal interface and acquisition equipment will be realizable.

Non-Deployed Horizon Sensor

The current horizon sensor utilized on Baseline Point Design Tug (1976 technology) must be deployed outside the vehicle moldline in order to obtain an adequate field of view. The mechanism required might be somewhat troublesome from a reliability/maintainability standpoint and elimination of the deployment requirement would constitute a distinct improvement. While this item was not considered serious enough to warrant a special SR&T development item, it is believed that further research in conjunction with Tug and possibly other programs post-1976 will result in a seeker which does not need to be deployed.

Reduced Avionics Weight

Again, the general trend in Avionics/electronics is steadily toward miniaturization and reduced power and heat rejection requirements. It would be expected, then, that in the post-1976 time period normal evolutionary development of avionics equipment will permit substitution or replacement of Tug avionics equipment such that reduced system weight will result It is believed that the post-1976 time period is far enough away that a specific recommendation for SR&T development on this item would be impractical.

Dedicated Guidance and Navigation Computer

Developments in subminiaturized G&N components should continue post-1976 and should result in very compact computers. Use of such a computer dedicated for G&N functions would reduce software programs and make GN&C reprogramming easier, and could conceivably free the DMS computer for other tasks. The result might be a slight weight reduction but more likely would be a somewhat simplified and more versatile/flexible overall avionics capability.

3.5.3 ALTERNATE DESIGN TECHNOLOGIES

A number of alternate technologies could be utilized in order to emphasize some valuable characteristic or feature more than was done in the Baseline Point Design system choices. These gains may be in increased versatility, increased reliability/mission success probability, lower development or production cost, less development risk, etc. The following discussions treat some of these which are believed to be of interest and should be considered in future studies before final Tug definition. It should be realized that most of these alternative technologies involve increased weight and therefore are desirable for reasons other than performance improvement.

Conventional Aluminum Shell Structure

As an alternate to use of advanced composite structure as in the baseline design, more conventional (1972 technology, for instance) aluminum structure could be utilized. This choice may be based upon the desire to reduce development cost/risk and fabrication cost. It has been estimated that the Tug Baseline Point Design outer shell could be fabricated of conventional 2418 aluminum and still meet payload performance goals, although the present Baseline positive margin of performance would be greatly reduced as a result of the increased inert weight with aluminum.

Multiple Engines/Increased Engine System Redundancy

One possibility as an alternate to the Baseline Point Design configuration in the propulsion area would be the use of multiple engines or more component redundancy to achieve higher mission success probability. Use of two engines, for example, could improve reliability if fully redundant, but at the cost of increased complexity in feed and start systems, engine mounts, and increased total engine installed weight. Also, the use of two smaller engines may result in reduced specific impulse because of the dropoff in performance with decreased thrust in the region of 5000-15000 lb thrust. This reduction could be on the order of 0.5 to 1.5 seconds. The combination of higher installation weight and reduced performance makes this option attractive only if reliability improvement becomes very important to the program.

Automatic Rendezvous and Docking

A completely automatic rendezvous and docking subsystem is very close to the subsystem concept recommended for the Point Design. All that is needed is the addition of logical software for docking, since the rendezvous phase is already automatic. The additional computer programs would handle both the circling and closure phases of docking. The television system could be retained (or simplified) to permit visual inspection of the target, and manual override, if desired. An automatic system concept was studied during 1971 for the Orbit-to-Orbit Shuttle (OOS), and was found to be feasible.

Data Management Hardwire

The current Data Management Subsystem uses a data bus to connect the computer to all other electrical and electromechanical equipment aboard the Tug by means of interface electrical units. Although the data bus, a set of wires, has insignificant weight, the interface units are heavy. An alternate arrangement is to centralize the interface units, which has the effect of trading separate component housing and bracketry weight for additional wire weight. This trade can only be beneficial in short vehicles with centralized avionics, as is the case with Tug.

SECTION 4.0

MANUFACTURING

The data contained in this section provides supporting information for verifying the Tug program approach and for estimating program costs. This programmatic information prescribes preliminary requirements in the area of manufacturing which will serve as a basis for expansion in future phases of the program. The limited production concepts that are described herein are possible and logical for the fabrication and assembly of the Space Tug and associated test vehicles. In developing these concepts, emphasis has been placed on making maximum use of existing contractor facilities, test equipment, and previously developed capabilities and techniques. Where existing technologies do not appear adequate, areas have been identified in the Technology Development Plan for advancement prior to 1976. The rationale for identifying specific manufacturing activities for advancement has been based on related experience of the contractor.

4.1 MANUFACTURING SCHEDULE AND FLOW PLAN

The total manufacturing flow time for a single Tug vehicle, from material procurement through final assembly, checkout, and preparation for shipment, is thirty-three months. This time represents a normal manufacturing flow for a single shift operation and is intended to convey neither a minimum nor a maximum time requirement. The schedule shown in Figure 4.1-1 indicates the time required to fabricate the major vehicle structures, i.e. the Liquid Oxygen (LOX) tank, the Liquid Hydrogen (LH_2) tank, the forward skirt, the intertank structure, the aft skirt, and the adapter (Tug to Shuttle).

For simplicity of presentation, the LH_2 tank and the intertank structure are indicated as the components of one major subassembly, and the LOX tank and aft skirt comprise a second. These two subassemblies, when completed, are mated and enter the final assembly process where the forward skirt, main engine, and auxiliary control propulsion system thrusters are installed. During the final assembly operation the adapter will be fitted to the Tug structure but removed prior to shipment.

The manufacturing flow plan, shown in Figure 4.1-2 was prepared in conjunction with the manufacturing schedule and depicts the sequences of operations used as a basis for preparation of the schedule. The flow plan portrays sequences for special detail fabrication, assembly, and final check-out. It also provides examples of special tooling that will be required for production of the Space Tug.

In subsequent paragraphs of this section, key activities of the manufacturing process will be discussed and referenced to sequences of the manufacturing flow plan.

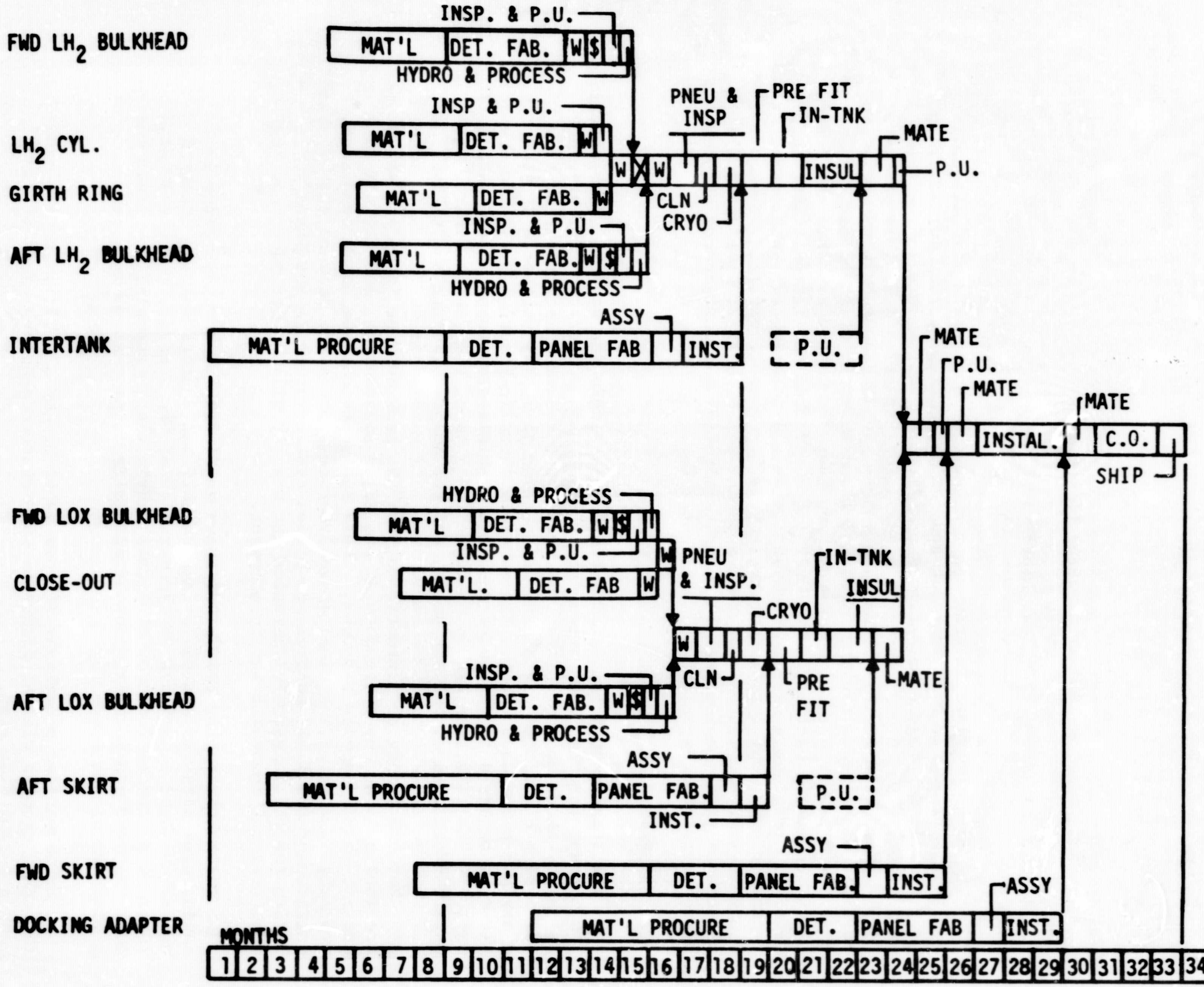

Figure 4.1-1 Manufacturing Schedule (Typical)

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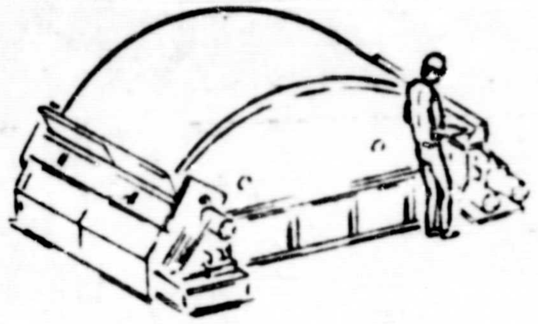
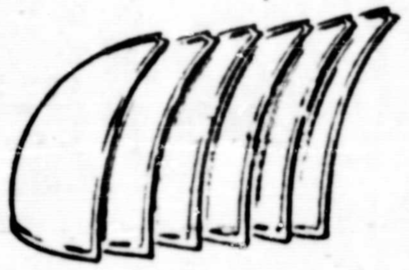


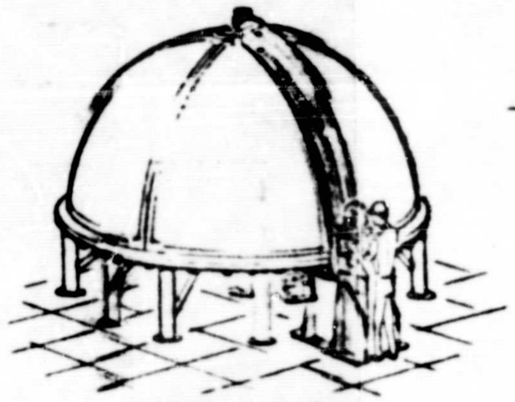
- STRETCH FORM GORE PANELS (LOX & LH2)

A.



- ROUGH TRIM GORE PANELS
- CHEM MILL

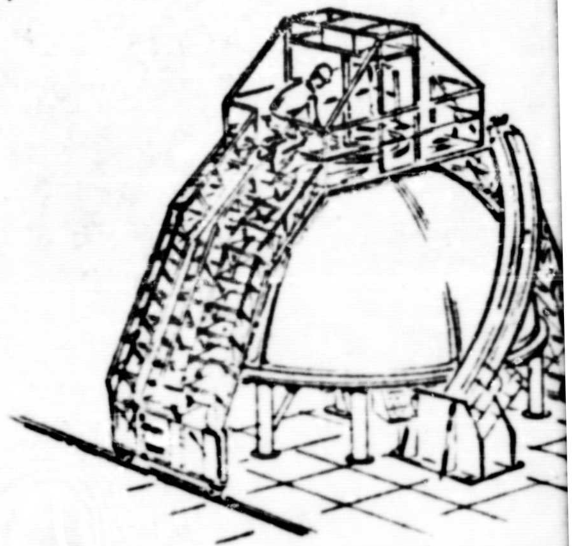
B.



BULKHEAD GORE WELD

- TRIM & WELD GORES TOGETHER

C.



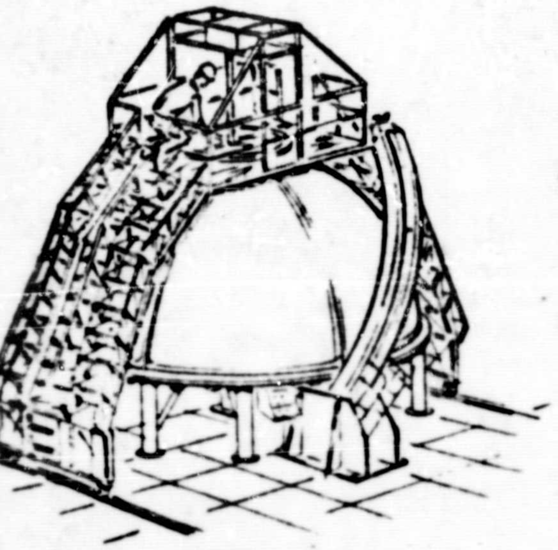
DOLLAR WELD

- TRIM & WELD DOLLAR & CLOSE OUT RINGS TO BULKHEADS

D.

STEP 1.

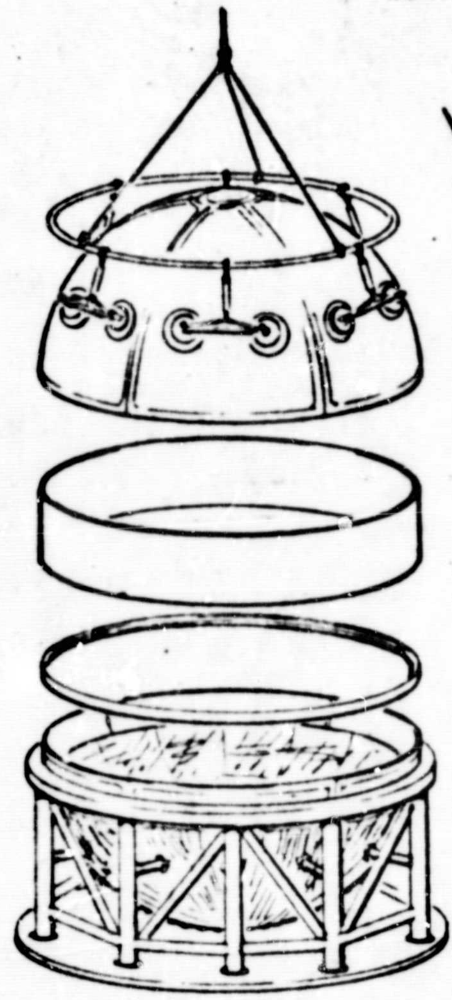
F-1



DOLLAR WELD

- TRIM & WELD DOLLAR & CLOSE OUT RINGS TO BULKHEADS

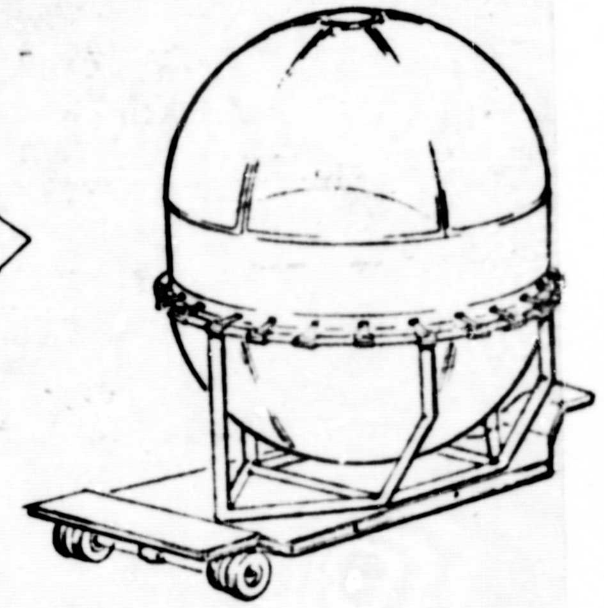
D.



GIRTH WELDS

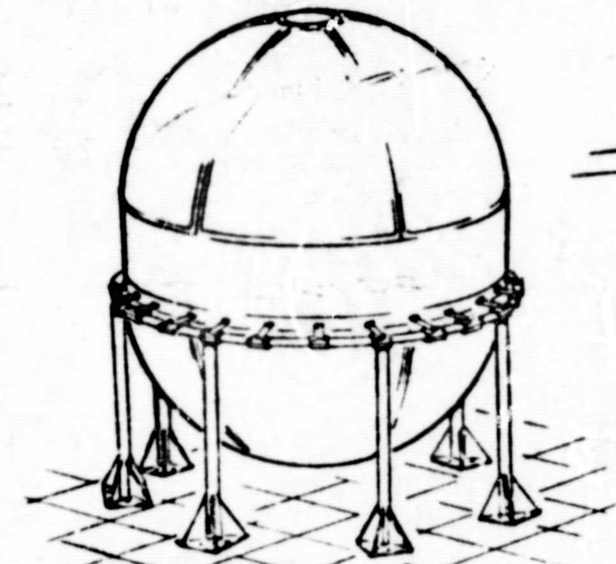
- GIRTH RING TO LOX TRIM & WELD
- TRIM & WELD GIRTH RING & SHORT CYLINDER ASSEMBLY TO LH_2 BULKHEADS
- UTILIZE STANDARD WELD POSITIONER

E.



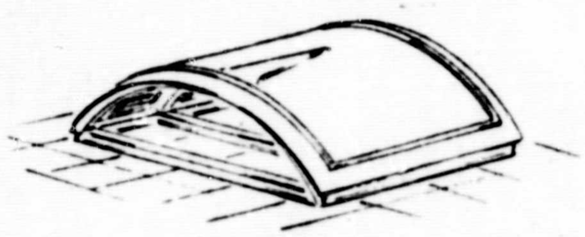
- PNEUMOSTAT TEST LOX & LH_2 TANKS

F.



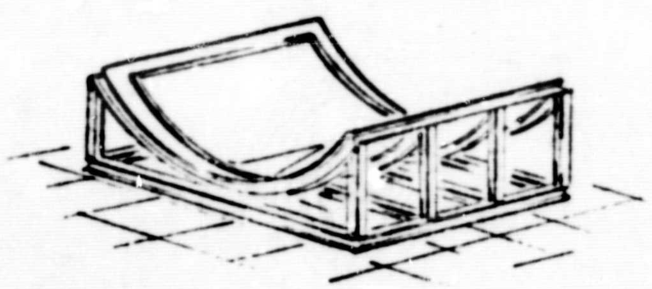
- POST PNEUMOSTAT INSPECT
  CLEAN LOX & LH_2 TANKS CRYOPROOF TEST

G.

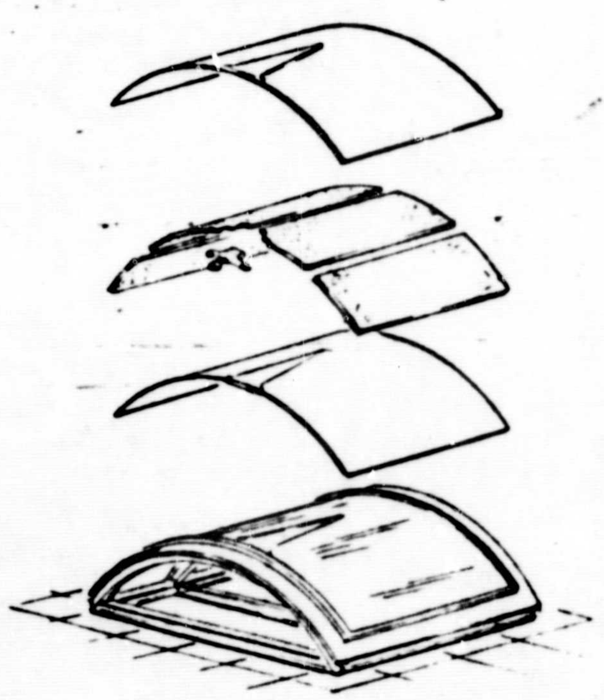


- LAYUP EXTERNAL SKIN ASSEMBLY

STEP 1.

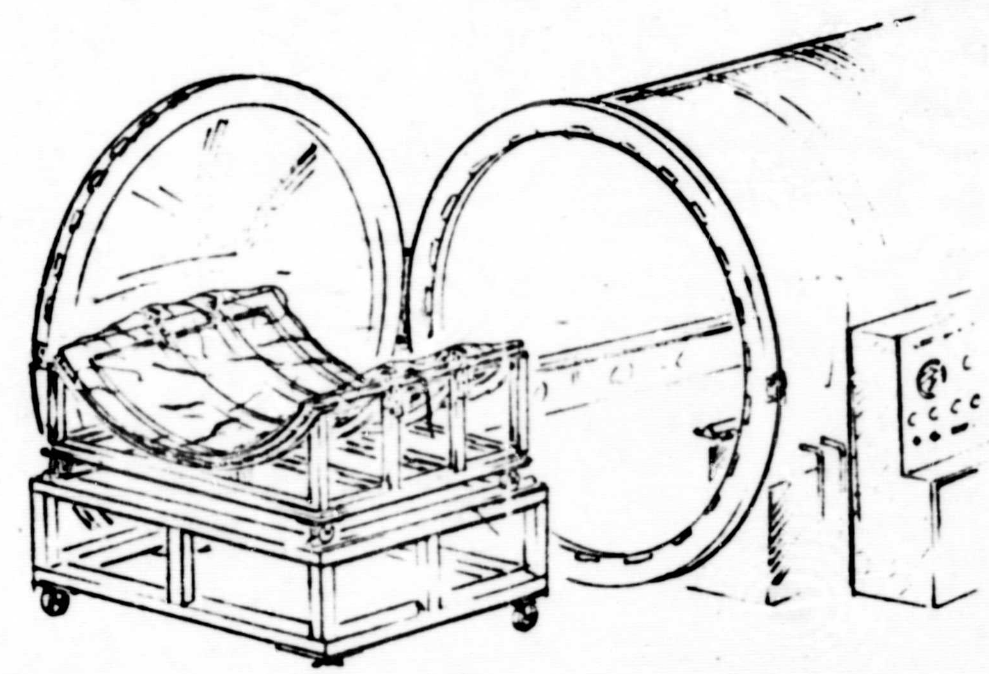


- LAYUP INTERNAL SKIN ASSEMBLY



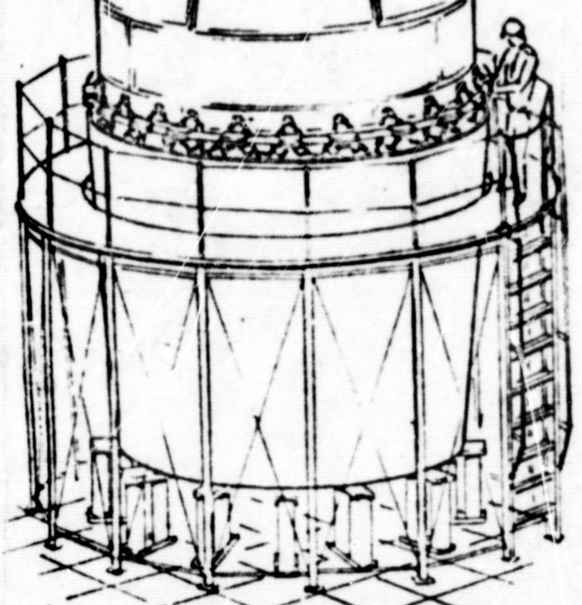
- BOND SKIN ASSEMBLIES TO HONEYCOMB & FITTINGS

STEP 2.



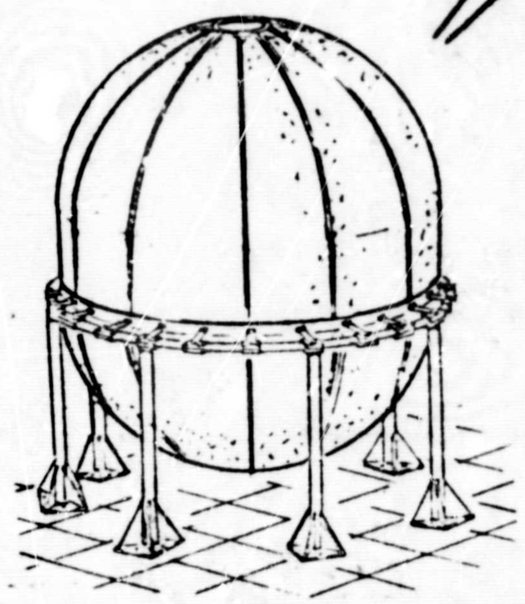
- SECONDARY BOND OF FRAMES TO SHELL HONEYCOMB PANELS

STEP 3.

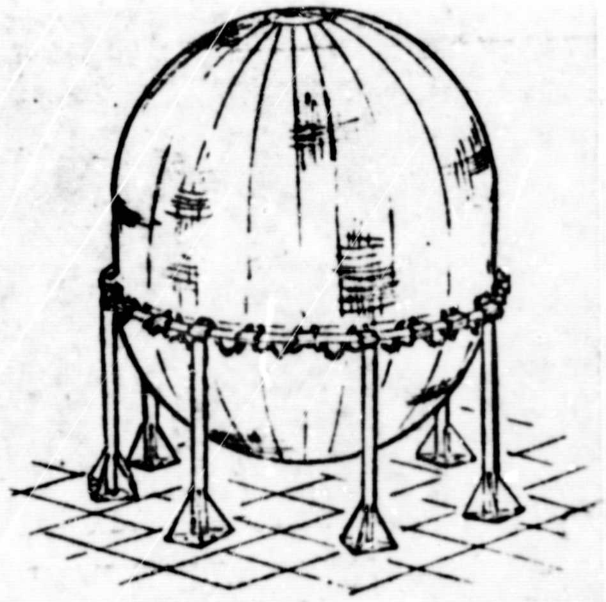


- PRE FIT LH2 TANK IN INNERTANK STRUCTURE
- PRE FIT LOX TANK IN AFT SKIRT
- PRE FIT TUBULAR TRUSS SUPPORTS
- INSTALL THRUST STRUCTURE & ENGINE SUPPORT FITTINGS ON LOX TANK

H.

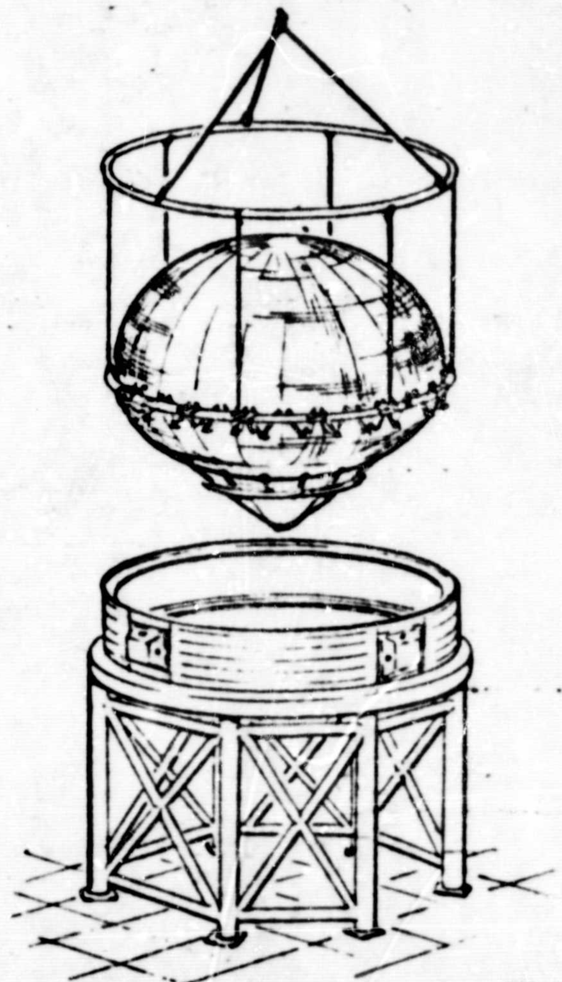


CRYO TEST - PEEL OFF SPRAY FOAM INSULATION



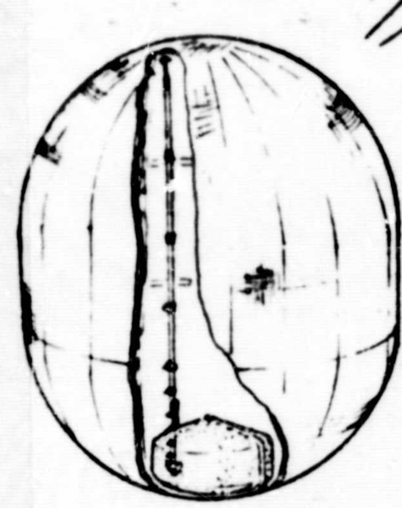
- INSULATE TANK STRUCTURE

I.

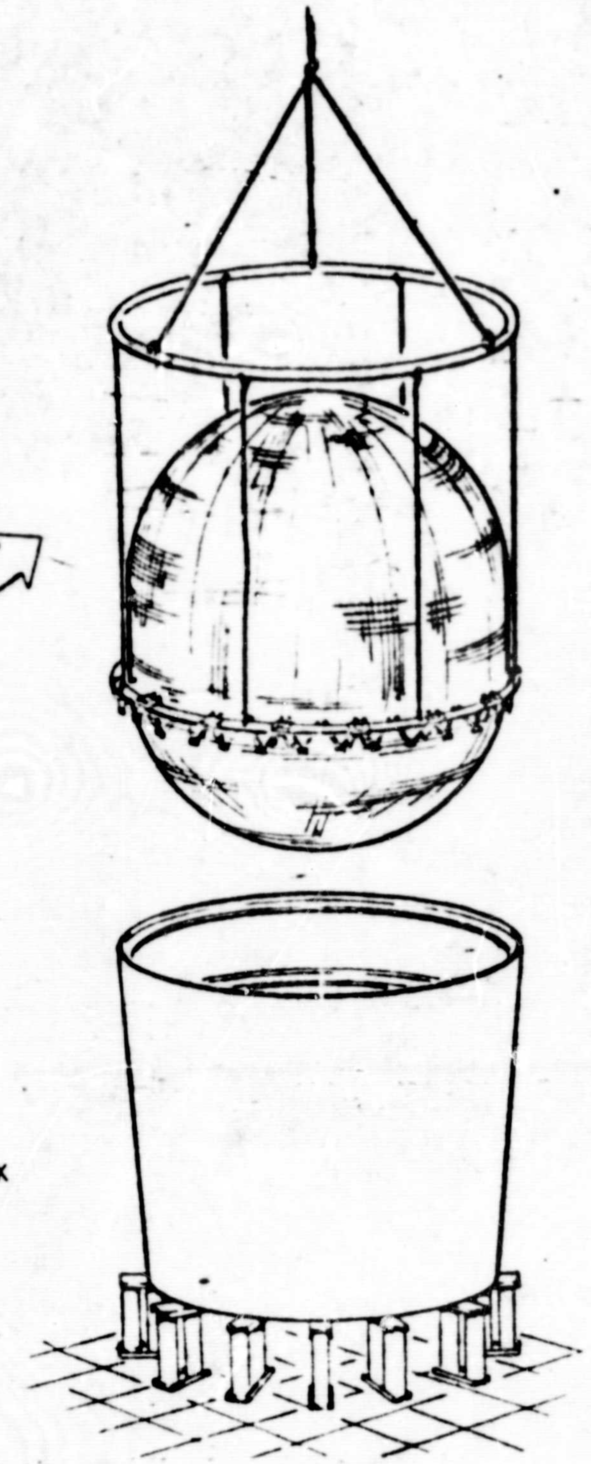


- INSTALL LOX TANK IN AFT SKIRT ASSEMBLY

J.

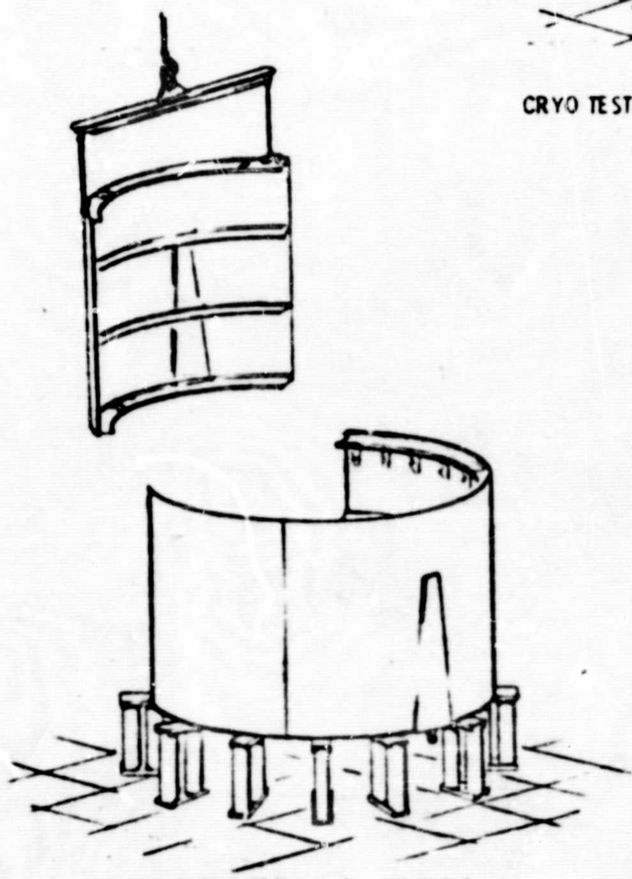


- TYPICAL INSTALLATION OF START TANK & STILL WELL ON LH_2 & LOX TANK



- INSTALL LH2 TANK ON INNER TANK STRUCTURE
- CONNECT TUBULAR TRUSS SUPPORTS

K.

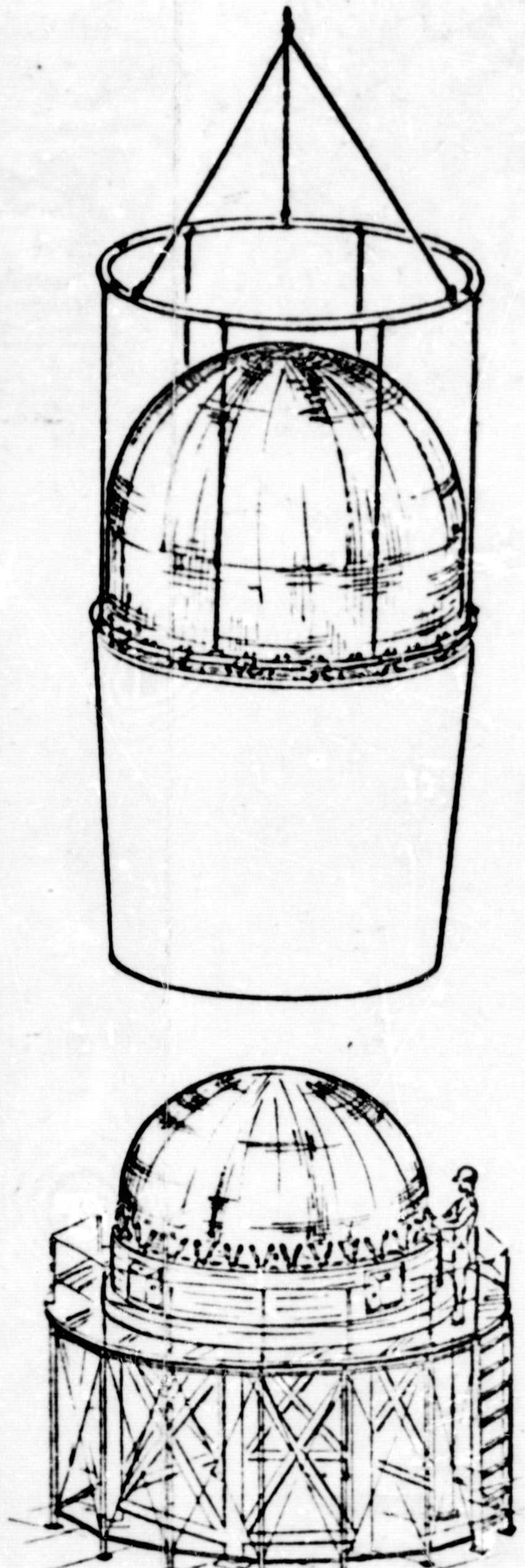


- ASSEMBLE PANNEL SEGMENTS

STEP 4.

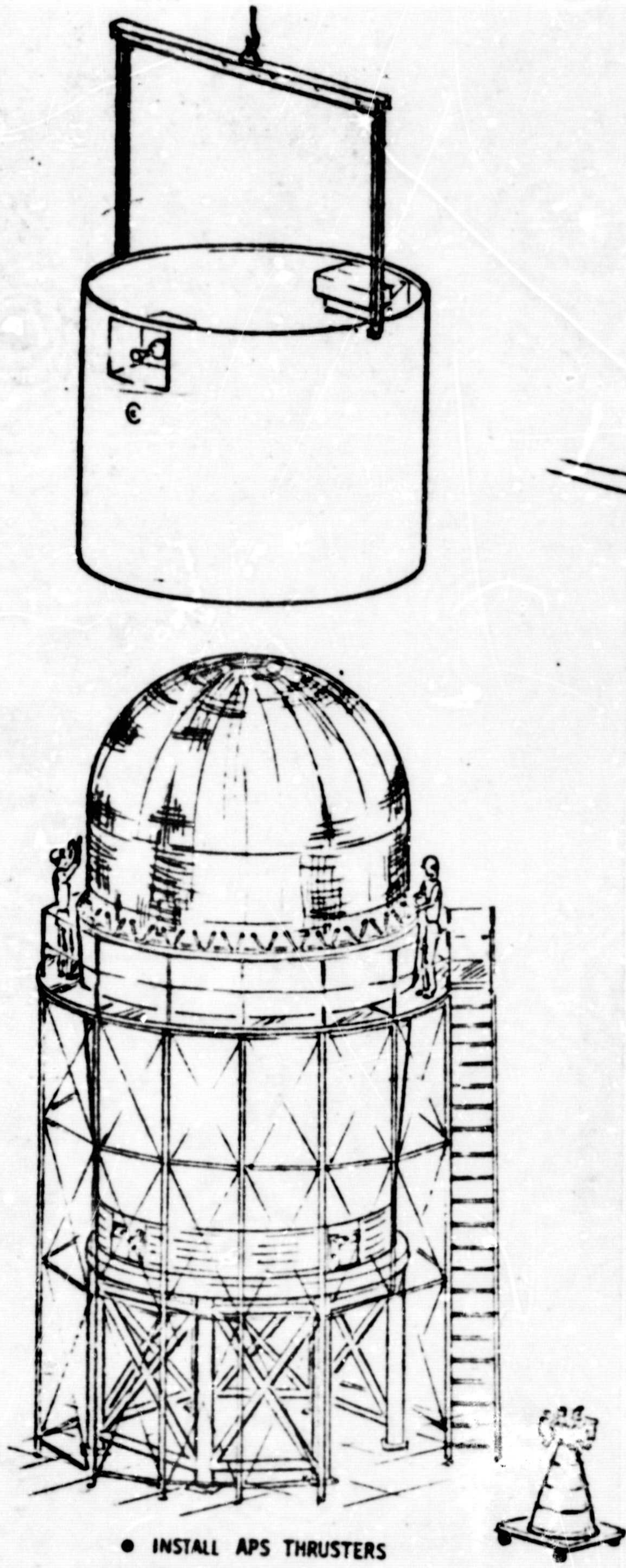
- INSTALL INNER
ASSEMBLY ON
- INSTALL LOX

START INSTALLAT



- INSTALL INNERTANK STRUCTURE & LH2 TANK ASSEMBLY ON THE AFT SKIRT
- INSTALL LOX & LH2 FUEL LINES

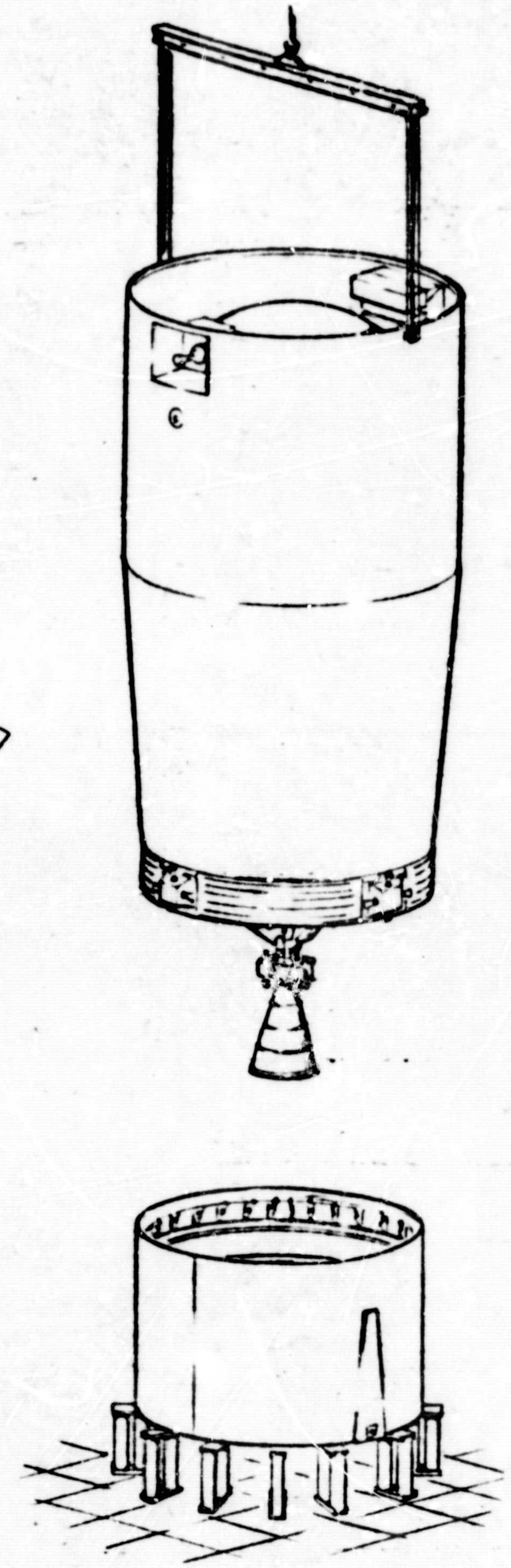
L.



- INSTALL APS THRUSTERS
- INSTALL FORWARD SKIRT
- INSTALL ENGINE
- CONNECT FUEL LINES

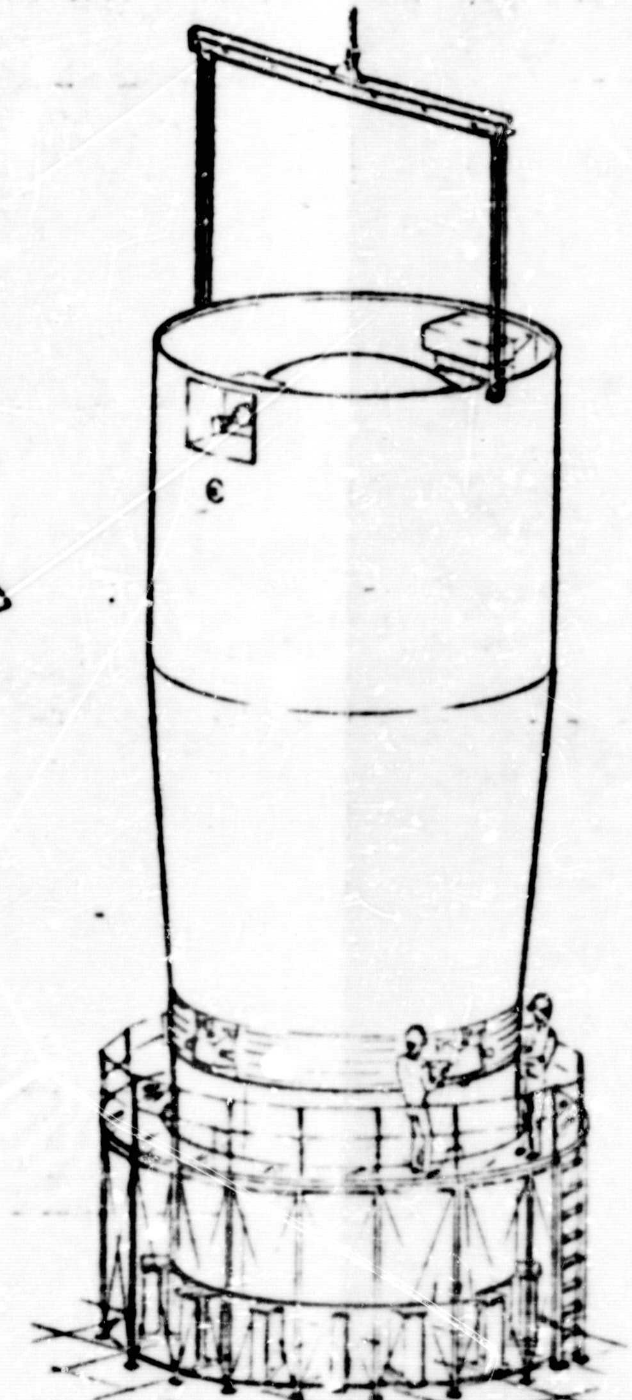
M.

TART INSTALLATION APS EQUIPMENT & AVIONICS



- INSTALL UPPER ASSEMBLY ON ADAPTER
- CHECK OUT SEPARATION & DOCKING MECHANISM

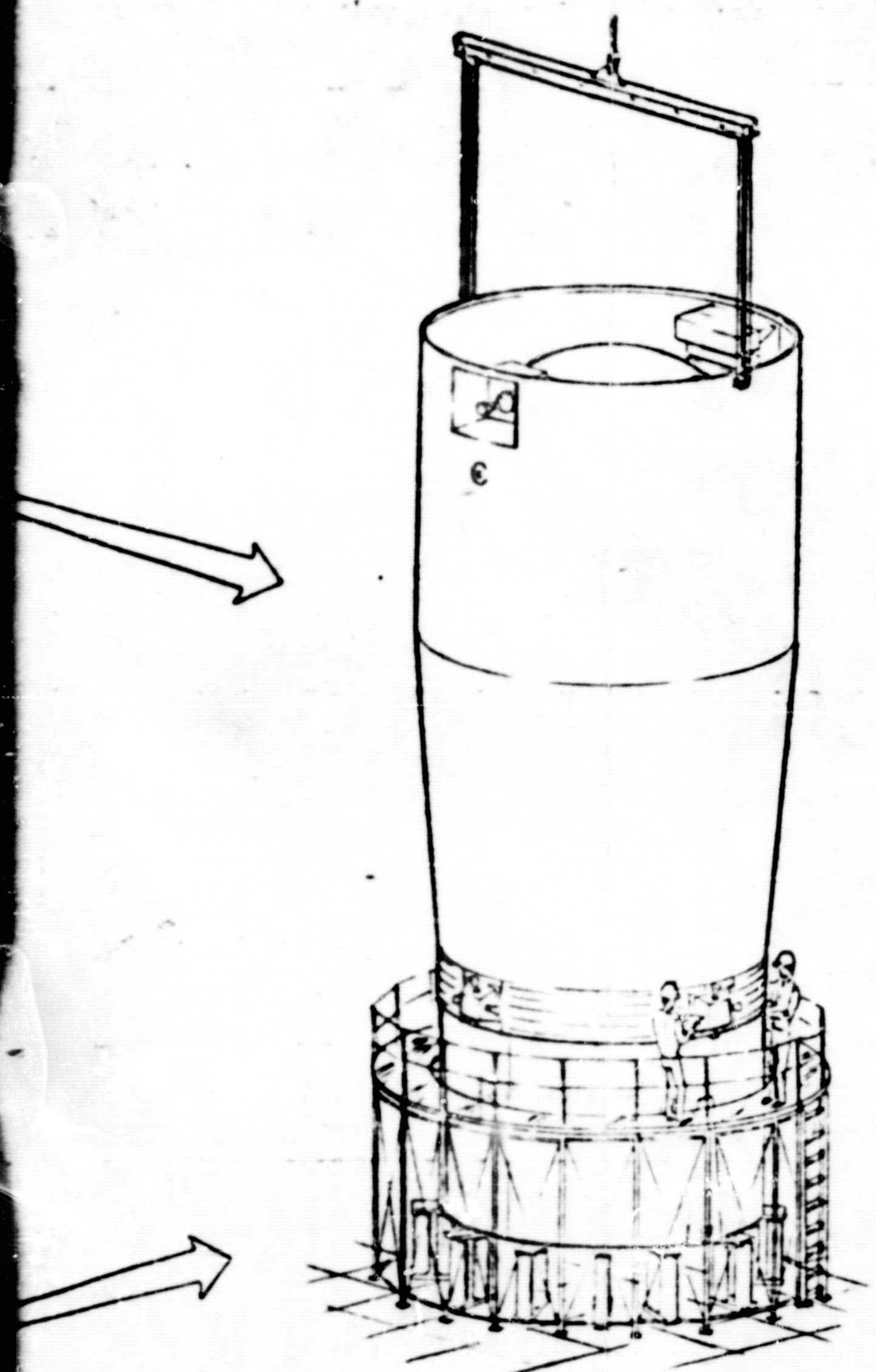
N.



- ASSEMBLY COMPLETE
- SECURE LATCHES
- FINAL CHECK OUT

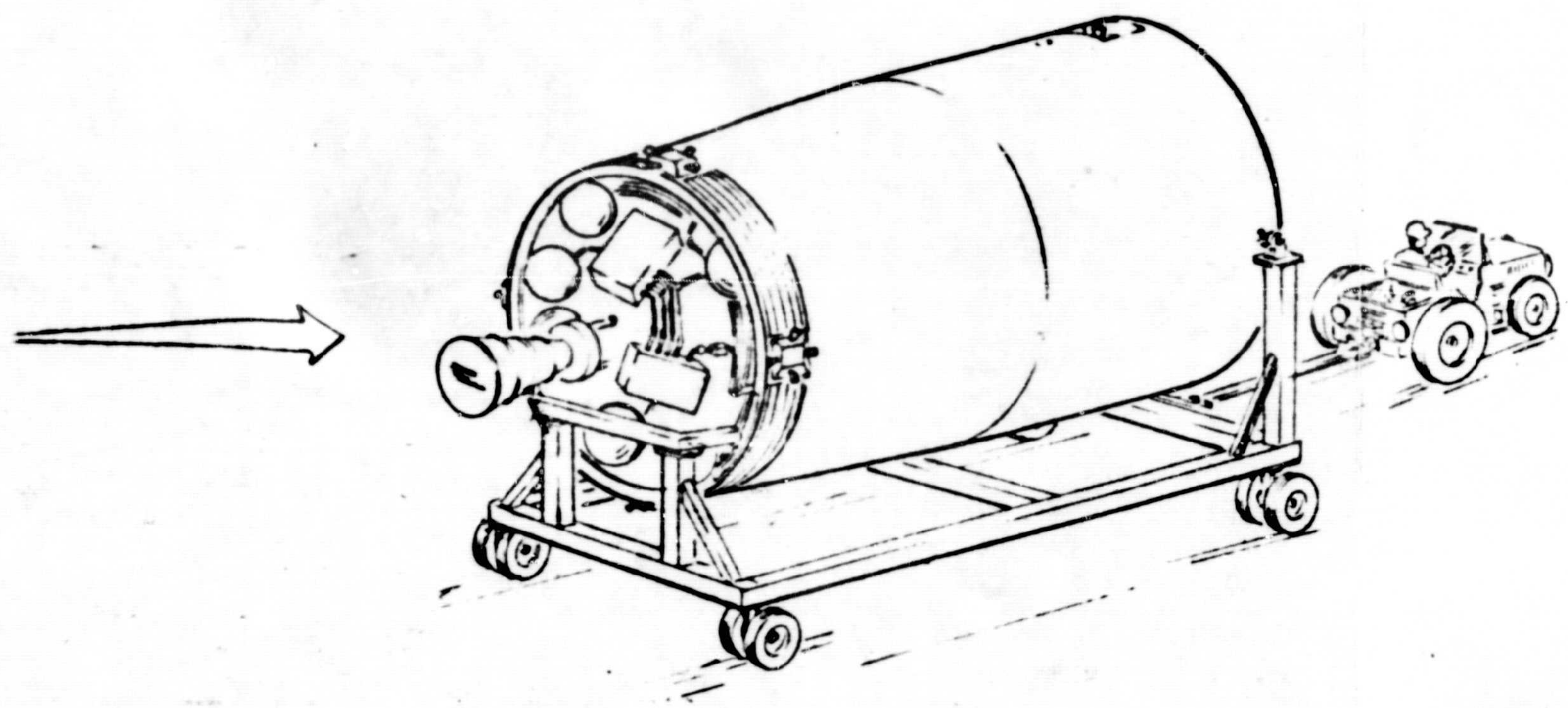
O.

F-4



- ASSEMBLY COMPLETE
- SECURE LATCHES
- FINAL CHECK OUT

O.



- SHIP TO ORBITER LAUNCH SITE

P.

Figure 4.1-2 Manufacturing Flow Plan

F-5

4.2 TANK FABRICATION AND ASSEMBLY

The Liquid Oxygen (LOX) and Liquid Hydrogen (LH_2) tanks will be fabricated from 2014T6 aluminum alloy. The spheroidally shaped tank ends or bulkheads will be formed from six gores of aluminum alloy. Each gore will be fabricated by stretch forming, profiling, and then chem-milling to a thickness of 0.025 inches at the apex, increasing to a thickness of 0.125 inches at the equator. The LH_2 tank cylindrical center section will be machined, rolled, profiled, and chem-milled from the same alloy used for the tank bulkheads. The design of the LOX tank does not require a center section. It will be formed by using a girth ring to mate the two tank ends together.

In forming the tank bulkheads, the gores will be set up, trimmed, welded, and X-rayed. Once formed, they will be hydrostatically pressure tested in the dome configuration. Upon successful completion of the pressure test the complete tanks will be formed by loading the bulkheads into an assembly weld tool and installing the appropriate girth rings or center sections.

After the tanks are X-rayed for weld conformity to specification, they will be transported to the pressure test facility where they will undergo pneumostatic, and cryogenic tests. After inspection and correction of defects, the tanks will be prefitted in the appropriate outer shell structure, i.e. LOX tank in the aft skirt and LH_2 in the intertank structure. The thrust structure will be installed on the LOX tank. Engine start tanks and still wells will be installed in both tanks prior to completion of insulation application.

The operations discussed in the foregoing paragraphs are portrayed in sequences A through H of Figure 4.1-2.

4.3 TANK INSULATION

A multilayer high performance insulation made of aluminized Kapton will be utilized to cover each of the tanks in order to minimize propellant boil off. A gas purge system will also be used to assist in maintaining insulation effectiveness.

Prior to arrival at the insulation work station the spray foam insulation used for cryo-proof testing will be peeled off, and a central manifold and feeder purge system will be fitted to each tank. The fiberglass ducts of this system will be adhesive bonded to the metal tank surface. Upon completion of the attachment of the purge system, the tanks are ready for installation of the insulation.

To provide support for the layers of insulation and to maintain a purge area between the tank and the insulation, a series of hardspots will be bonded to the tank surface. An aluminum screen will be attached to the hardspots to serve as a base for mounting the layers of insulation modules.

The insulation modules are formed from five sheets of aluminized Kapton, each two mils thick, cut in the shape of the tank gore sections. Six layers of modules are applied in a staggered fashion over the aluminum screen support. Each layer is overlapped and heat fused at the tab fastening points to provide a secure seal. Attachment posts are then installed through the layers of insulation and threaded into each of the supporting hardspots to prevent movement of the insulation. Hook and pile will be used to seal insulation joints around access panels.

A plastic membrane is applied over the completed insulation to serve as a protective covering.

A cross section of the insulation is shown in Figure 4.3-1.

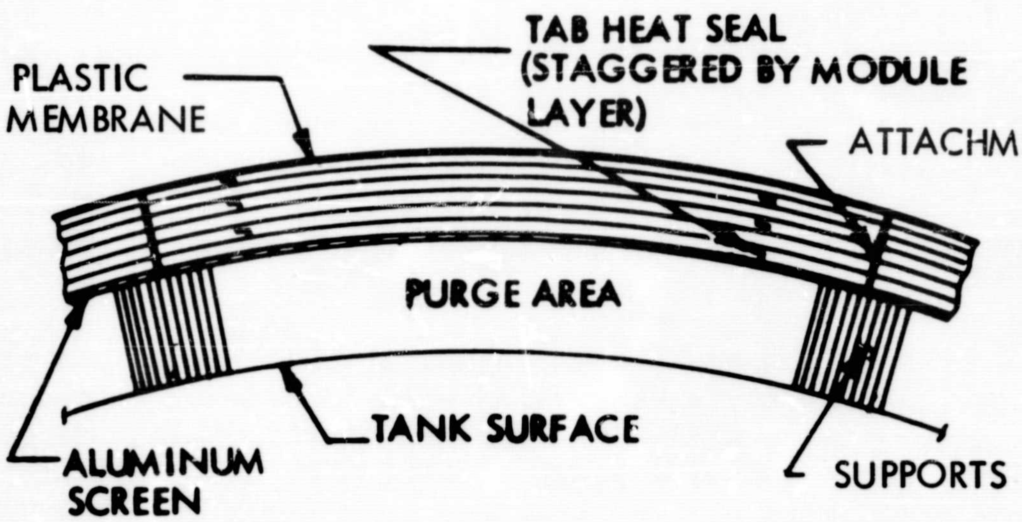


Figure 4.3-1 Insulation Cross-Section

4.4 SKIN PANEL FABRICATION

To achieve an optimized relation of maximum strength and minimum weight for the outer shell sections of the space Tug a combination of graphite epoxy laminates bonded to aluminum honeycomb will be used. The laminates will be formed from layers of preimpregnated graphite epoxy interlaid in an isotropic pattern of 0°, +45°, -45° and 90° to form sheet material of varying thicknesses from 0.008 inches to 0.125 inches.

These sheets of graphite epoxy will be formed in special lay-up fixtures preparatory to bonding to both sides of an aluminum honeycomb core. After this primary bonding, a secondary bond, utilizing an autoclave to provide controlled heat and pressure, will assure firm bonding of the skin panels to the honeycomb core.

Similar applications of the graphite epoxy laminates, without the aluminum honeycomb core will be used to fabricate the micrometeoroid shield, and structural support members for the outer shell sections.

The fabrication of skin assemblies is illustrated in steps 1 through 3 of Figure 4.1-2.

The fabrication of Space Tug assemblies from graphite epoxy is within current technology and presents no major manufacturing problems. However, to supplement the present manual method of fabrication, tooling should be developed to provide a mechanical means of applying graphite epoxy over large areas and of ensuring uniform reproducibility of struts, tubes, frames and sheets.

4.5 OUTER SHELL ASSEMBLY

The outer load-bearing shell structures (the forward skirt, the intertank structure, aft skirt, and the adapter) will each be fabricated by assembling four of the graphite epoxy skin panels. These panels are spliced and mechanically fastened by a series of bolts at each joint. The shell structure sections are reinforced with graphite epoxy "C" shaped frames bonded to the interior surface. An example of this assembly is shown in step 4 of Figure 4.1-2.

Alignment holes for the docking latch mechanism, the docking probe, and the helium supply tank for the purge system will be drilled in the adapter assembly. Locations will be drilled in the aft skirt assembly for the docking drogue and latching receptacles, support fittings for the LOX tank, the auxiliary control propulsion system thrusters, and the micrometeoroid shield and purge wall. Locations will be provided on the intertank structure for the LH_2 tank support fittings, the cargo bay umbilical panel, and an access door.

On the forward skirt assembly alignment holes will be drilled for the docking latch mechanism, docking probe, avionics equipment, and a purge pressure meteoroid barrier.

After the shell assemblies have been fit checked with each other they will be separated and routed to the final assembly area for installation of the electrical, mechanical, and fluid systems indicated above.

4.6 MAJOR ASSEMBLY

Major assembly is depicted in sequences J, K, and L of Figure 4.1-2. It follows the completion of outer shell fabrication and application of tank insulation. At this point required bracketry, fittings and avionics will have been installed in the outer shell assemblies. Tests will have been conducted during the subassembly processes to assure proper functioning of the subsystems.

The primary effort to be accomplished during major assembly involves (1) installation of the LOX tank in the aft skirt assembly, (2) installation of the LH_2 tank in the intertank structure, and (3) mating of the completed intertank and aft skirt assemblies.

Concurrent with the major assembly sequence, tubular truss supports will be connected, LOX and LH_2 fuel lines will be connected, and the micrometeoroid shield and purge wall will be adjusted and connected.

4.7 FINAL ASSEMBLY AND CHECKOUT

Final assembly and checkout is portrayed in sequences M, N, and O of Figure 4.1-2. Final assembly includes (1) the installation of the forward skirt on the tank assemblies, (2) installation of the purge pressure meteoroid barrier in the forward skirt (3) installation of the auxiliary control propulsion system thrusters, and (4) installation of the main engine and connection of the fuel lines.

As a part of final checkout the complete Tug will be installed on the adapter for fit-check and checkout of the separation and docking mechanism. Prior to shipment of the assembled Tug, the adapter will be removed for separate shipment. Final checkout also includes a check of all wiring and tubing previously installed during individual sub-assembly operations.

Final checkout by Manufacturing will be followed by Post-Manufacturing checkout as described in Section 5.0, Test Operations.

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SECTION 5.0

TEST OPERATIONS

5.1 INTRODUCTION

The Space TUG Point Design Test Section describes a disciplined, integrated and cost-effective approach for the development and qualification of the Space TUG hardware. It recognizes the experience gained from similar North American Rockwell related programs. The objective of the planning is to identify the test requirements and define the Space TUG test concepts and philosophy necessary to assure operational reliability at the least cost.

This section describes the planning, analysis, and testing to be accomplished during the test program. The major test classes, articles, and resources are discussed. Engineering development tests, qualification and higher assembly tests, subsystems and major articles are discussed in terms of gross requirements, criteria, methods, overall planning, and broad objectives for each test class or phase. The implementation of an integrated test program includes a development-type approach and acceptance test phase at the materials, components, subassembly, subsystem and major test and flight article levels.

5.2 TEST PHILOSOPHY AND CRITERIA

The test philosophy and criteria consist of a set of ground rules which assist in formulating design requirements as well as test, checkout and operational requirements. These groundrules establish a base upon which to develop test logic and a test program to meet the objectives of cost-effectiveness, versatility, reliability, maintainability and safety. A major program goal is to obtain the desired confidence at each testing level with a minimum of major test articles and within schedule constraints. Program test philosophy will be structured to accommodate major test categories with inherently different disciplines and emphasis. Development tests require a highly flexible approach so that configuration and operating or checkout procedures may be optimized during the process. Acceptance tests require a rigorous application of controls to ensure that all elements of the Space TUG system, including software, meet the established requirements.

5.2.1 Test Criteria

Test philosophy and criteria outlined below have been developed to allow maximum use of all test data to satisfy the design verification requirements,

and is aimed at establishing an integrated test program which will accomplish the basic objective of achieving adequate confidence at minimum cost.

1. Test requirements will be structured to identify and accumulate data for key component and subsystem parameters throughout all phases of testing. This data, along with applicable data from other space programs, will be incorporated into a central data bank for use in anomaly resolution, trend establishment, and checkout procedure refinement.

2. Test equipment, checkout procedures, and data accumulation will be standard wherever possible throughout all phases of testing. The on-board computer system will be the primary mode for accomplishing system testing.

3. The test approach will utilize past program experience to achieve maximum efficiency and avoid costly failures. The object of this approach is to reduce test costs by avoiding redundant support equipment requirements, and fully utilize pertinent data available from other development and qualification test programs.

4. Cost effectiveness will be a prime consideration in establishing the test program.

5. The test logic network for the subsystems, vehicle and program will contain specific indicators where management review and approval are scheduled prior to proceeding into the next phase of testing. These indicators will be keyed to critical program milestones wherever possible.

6. Acceptance test requirements will be traceable to the Space TUG system and/or contract end-item (CEI) specifications.

7. Flight test instrumentation (where required) will be installed and removed without significantly impacting the on-board checkout system or data acquisition system.

8. On-board telemetry calibration verification of vehicle subsystem and test equipment for orbital operations will be used for manufacturing through prelaunch ground operations.

9. All software programs for test and checkout will have interim entry points for start/stop and/or troubleshooting.

10. The flight test vehicle configuration will be identical to that of the operational vehicle except for additional instrumentation.

11. The maximum practical use of commonality will be employed for test methods and procedures, test equipment, support equipment, facilities and operational techniques.

12. Special testing for reliability data and performance confidence will be by exception only; this data will be obtained by acquiring operating time and failure trend data throughout the development, qualification, acceptance, flight and operational phases of the program.

13. Repetitive testing will be minimized through the test cycle from vendor manufacturing through end-item delivery to final customer.

14. Maximum use will be made of existing contractor and government test facilities where practical and cost effective.

5.2.2 Test Tolerance

A pass-fail criteria or acceptability tolerance, including margins of safety based on the test requirements, will be specified for all tests. The acceptance tolerance band or specified nominal test level will be based upon instrumentation accuracy, facility/ground support monitoring equipment tolerance, test specimen tolerance stack-up or expected variation from specimen to specimen depending upon manufacturing tolerances, external environment (pressure, temperature, humidity, etc.), test influence variations and other parameters as may be deemed necessary. A narrow tolerance band shall be imposed on the manufacturer's component or subsystem acceptance to provide an objective screen for workmanship. The tolerance band will be expanded for system checkout in consonance with the apportionment of the hardware's contribution to the total system tolerance limits. Subsequently, the tolerance limits will be expanded, based on vehicle test operations and other use experience, to values that will provide the desired mission results, plus a margin of safety.

5.3 TEST PROGRAM SUMMARY

The overall objective of the Space TUG Test Program is to qualify in an integrated, disciplined and cost-effective program, the components, subsystems, systems and Space TUG vehicle for their ability to fulfill the requirements dictated by the design and projected mission. To accomplish these objectives, sequential testing levels will be required to span the integration of initial materials testing through complete system testing. The test program consists of an integrated approach encompassing the following test elements:

1. Development tests

2. Qualification tests

3. Design verification tests

4. Acceptance test

5. Flight test

The integrated test program criteria will be based on providing a vehicle test capability for accomplishment of anticipated system and combined system test objectives. In determining test article requirements, the following test/program requirements are considered:

1. Structural tests
2. Dynamic tests
3. Cryogenic tests
4. Static firing tests
5. Integrated system test
6. Thermal vacuum test
7. Vibroacoustic tests
8. Facility and ground support equipment compatibility tests
9. Software development
10. Flight test

The identification of test articles will be established to provide a low risk test program, yielding a high level of confidence in the Space TUG vehicle design and the manufacturing process. In support of the test program, the following major test articles have been identified:

1. Structural test articles
    a. LOX tank
    b. LH_2 tank
    c. Outer shell
    d. Thrust structure
2. Battleship test article
3. Flight test vehicle

Structural Test Articles

The primary objective of the structural test program is the verification of structural integrity and establishing the design margin for operational limits. Subsequent to static testing, test articles will be refurbished and undergo dynamic testing consisting of vibration, shock and acoustic tests. The dynamic tests serve to confirm predicted vibration levels at critical locations and to qualify attachment design.

Battleship

The objectives of the battleship test article are to provide design information, demonstrate system adequacy and to evaluate system performance under cryogenic and simulated operational requirements.

Flight Test Vehicle

The flight test vehicle will serve as a test vehicle for the verification of planned inline operations, testing, processing and handling. The flight test vehicle will first undergo post-manufacturing checkout. Subsequent to post-manufacturing checkout, the flight test vehicle will be committed to a static firing test program. Major goals of the static firing program will be the verification of vehicle system compatibility and component integrity. Static firing data will supplement data acquired during the battleship test program. On completion of the static firing program the flight test vehicle will be transported to MSC (Houston) for thermal-vacuum testing. The flight test article will then be shipped to the launch site and committed to the flight test program.

5.4 DEVELOPMENT TESTING

Development testing is that testing conducted to select and prove the feasibility of design concepts. Development testing is concerned with engineering evaluations of hardware, software, and manufacturing processes and techniques for the purpose of acquiring engineering data, identifying sensitive parameters, and evaluating the development configuration performance. Development testing also provides the necessary confidence that the hardware will meet the specifications requirements and the manufacturing processes will produce an acceptable product. Development testing encompasses materials selection and characterization, process evaluation, design feasibility determination, and overall vehicle design and configuration verification, including that for major test article and model tests.

Test Criteria

The test criteria to be applied during the engineering development test phase are:

1. Development requirements will be satisfied by the maximum use of analysis, supported by development tests or a combination of both.

2. Development of checkout and maintenance plans and procedures will be accomplished during subsystem development and verified along with operational procedures during the test program.

3. Structural testing of major test articles will establish a satisfactory design margin for operational levels.

4. Testing will be structured to provide initial information on maintenance, parts replacement, and projected service life requirements.

5. Early subsystem integration with the computer operational phase software will be a key test program goal.

6. Overstress testing, when required for operational analysis or design and manufacturing verification, will be conducted at the completion of the development program utilizing development hardware. Overstress and off-limit conditions may include both increased time at qualification levels and increased severity of the applied stress or condition as applicable.

7. Acceptance tests, procedures, equipment, and test levels will be established and verified during development testing to the maximum extent possible.

8. Where new materials or existing materials under new conditions are to be used, adequate testing shall be performed to statistically identify material property values.

9. Application of any new non-destructive testing techniques will be proven and verified during the development test program.

10. EMI/EMC testing will be accomplished primarily at the component or subsystem level and data will be accumulated for subsequent installed subsystem susceptibility assessment. This will be accomplished as part of the manufacturing "in-process" test and integrated vehicle checkout activity.

Development Test Requirements

For end-item hardware which is to undergo development testing, test requirements will encompass the following as a minimum:

1. Verification of design and performance capability, including redundancy.

2. Verification of ability to meet mission requirements with adequate design margin.

3. Integration of each component and subsystem with other components, subsystems, facilities, and support equipment.

4. Verification of processes, procedures, equipment, and test levels for manufacturing, acceptance testing, maintenance, checkout and operational phases of the program.

5. Determination of significant failure modes and effects.

6. Determination of the effect of various combinations of tolerances and drift of performance parameters.

7. Determination of the effect of combinations and sequences of environments and varying stress levels.

8. Identification of safety hazards, parameters, requirements and procedures.

5.4.1 Propulsion and Mechanical

Components

All propulsion system component development tests will be performed by the respective vendors with the exception of the auxiliary propellant tank. The auxiliary propellant tank will be designed and built by North American Rockwell (NR). The following tests will be performed on the auxiliary propellant tank to assure proper design.

1. Ground Fill - Test will be conducted utilizing LN_2 to fill through the ground fill line, monitoring the fill rate and point sensor operation.

2. In-Flight Fill - Test will be conducted utilizing LN_2 to fill by opening the vent and monitoring the fill rate and point sensor operation. The screen performance and heat transfer will be monitored under a one-g environment. Analyses require the tank be mounted inside the larger propellant tank.

3. Drain - While immersed in larger tank, the feed will be opened to the reaction control system (RCS) and the flow rate monitored.

Zero-g Testing

Early Shuttle flights or Skylab flights will be considered as possible sources to determine performance of the APS tank screened inlet and collector tubes, gather tank heat transfer data and determine tank thermal dynamic characteristics in a Zero-g environment.

Subsystem

Subsystem tests will be performed at NR laboratories or at outside vendor laboratories to verify compatibility between system components and to assure proper system operation. Tests will encompass flow rates, component response time, and system response time. The pressure range and correct operation of regulators, pressure switches, relief valves and other pressure control devices will be verified along with leakage rates. The effect of cryogenic and vibration environment, where critical, will be evaluated along with system control characteristics, checkout, and purge capability and practicality.

5.4.2 Avionics

A group of avionic test assemblies will be assembled in order to subject them to testing for the investigation and development of the primary avionic systems. The subsystems will be assembled as an engineering breadboard.

The engineering development breadboard is a development tool used to demonstrate subsystem level and integrated system design and techniques. The breadboard provides design engineering with a test bed for the investigation, evaluation and verification of vehicle circuitry logic and performance functions. During breadboard development, software programs, procedures, and techniques will be developed along with the related ground support equipment (GSE). Test requirements and tolerances will also be developed within the limits of the breadboard test environment and schedule. Software programs, procedures, and techniques formulated provide a baseline test program element for the development of procedures to be used for vehicle flight acceptance. The pertinent test documentation, data requirements, and actual conduct of tests on the deliverable end-item evolve from the evaluation of engineering specifications, system reports, analytical techniques and system schematics.

5.4.3 Structures

The Space TUG structure consists of five major subassemblies: an outer shell structure, a thrust structure, a LOX tank, an LH_2 tank, and a forward support ring. In addition to the above subassemblies, there are tank supports and docking and latching mechanisms. The structural integrity of the vehicle will be established by analysis and verified by tests under a number of selected critical load conditions. Static and dynamic test verification is required for all of the subassemblies and mechanisms, defined above, of the vehicle to total mission life requirement. The structural test program will include material and process testing, structural development testing and structural verification testing.

Material and Process

Material and process testing will be performed as required to evaluate, characterize, select, and substantiate the selection of materials and processes for use in the structural subsystem. Areas to be investigated include the following:

1. The ability of seals, sealants, lubricants, and grease materials to function under mission requirements of temperature, pressure, loads, and exposure time.

2. Flammability, toxicity, smokability, LOX compatibility, and outgassing characteristics of candidate materials.

3. Performance of thermal control coatings under boost exposure.

4. Compatibility of materials in contact with each other in environments which may result in degradation in properties.

5. Effects on structure system of corrosion with regard to useful life of candidate materials.

6. Optimization of special welding techniques verified by mechanical and non-destructive tests.

7. Fabrication techniques for producing graphite epoxy honeycomb cylindrical panels.

8. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials.

9. Physical and mechanical properties of TUG materials which have not been previously established.

10. Joining methods for candidate alloys for TUG structural and thermal requirements.

11. Development, design, fabrication, and verification of the insulation for the TUG.

12. Demonstration of thermal performance, structural integrity, and materials compatibility of RCS plume impingement insulation.

Mechanisms and Attachments

Structural development testing will be performed to provide test data on critical or difficult to analyze areas early in the program. This will provide knowledge of internal load distribution in configuration complexity, load path redundancy, or high load dissipation.

This early testing will aid in minimizing weight and reduce the risk of premature failure of the major structural test articles. Major development test areas include:

1. Orbiter attach fittings and load diffusion structure

2. Docking and latching mechanism for both the payload and shuttle

3. TUG/payload deployment mechanisms

4. Composite to metallic joint design

Major Test Articles

Static. Four major structural subassemblies will be utilized for the conduct of the static test program. These test articles are: 1) outer shell, 2) thrust structure, 3) LOX tank, and 4) LH_2 tank.

Structural verification testing will demonstrate the vehicle structural integrity and compliance with design criteria by testing under the most critical load and environment conditions. Safe-life capability of the LH_2 and LOX tanks will be certified by subjecting the structure to pressure-cycling before ultimate load application.

The sequence of testing and the selection of test article configurations will be designed to gain the most critical information as soon as possible while attempting to minimize program risk and testing costs.

Outer Shell. Verification testing of the outer shell structure will be performed on a full scale test article consisting of the forward skirt, intertank structure, aft skirt and shuttle adapter. Shell loads and moments resulting from attached tankage and payload structures will be applied using hydraulic cylinders. Test fixturing will be utilized to simulate the tankage and payload stiffnesses when required for proper distribution or reaction of applied loads.

Maximum shell loadings are all derived from shuttle operations. Thus, the test applied loads must ultimately be reacted by structure simulating the shuttle cargo bay attach fittings. To best accommodate these loading requirements, testing will be performed with the outer shell test article in a vertical position as shown in Figure 5.4-1. Test support structures both internal and external to the shell are required to react and apply the loads. The LH_2 and LOX tank loads are introduced to the shell by means of rigid rings which distribute axial and lateral loads applied by the load cylinders. The concentrated moment from each tank is applied to the shell by varying the load magnitudes in the four axial load cylinders.

Payload axial load and moments are applied to the shell in a manner similar to that for the tanks utilizing twelve axial load cylinders. These act on the forward loading ring which also simulates the payload stiffness properties. Payload shear loads are applied to the forward loading ring by the payload lateral load cylinder. All shell lateral loads are reacted at the forward and aft ends by six reaction points attached to test support structure so as to simulate the shuttle installation.

By proper selection of load cylinder magnitudes, the critical shell loadings can be applied over the entire shell length. The most effective means of testing is to reproduce in this manner, envelopes of the maximum shell loadings. In this way, the maximum tension and compression shell loadings can be applied in two test conditions.

Because the load envelope encompasses two load cases in the aft skirt/adapter region, test loading will slightly exceed the theoretical design shell loading. This imposes no problems since practical considerations dictate the structure be designed to accommodate the linearly varying shell load in this area.

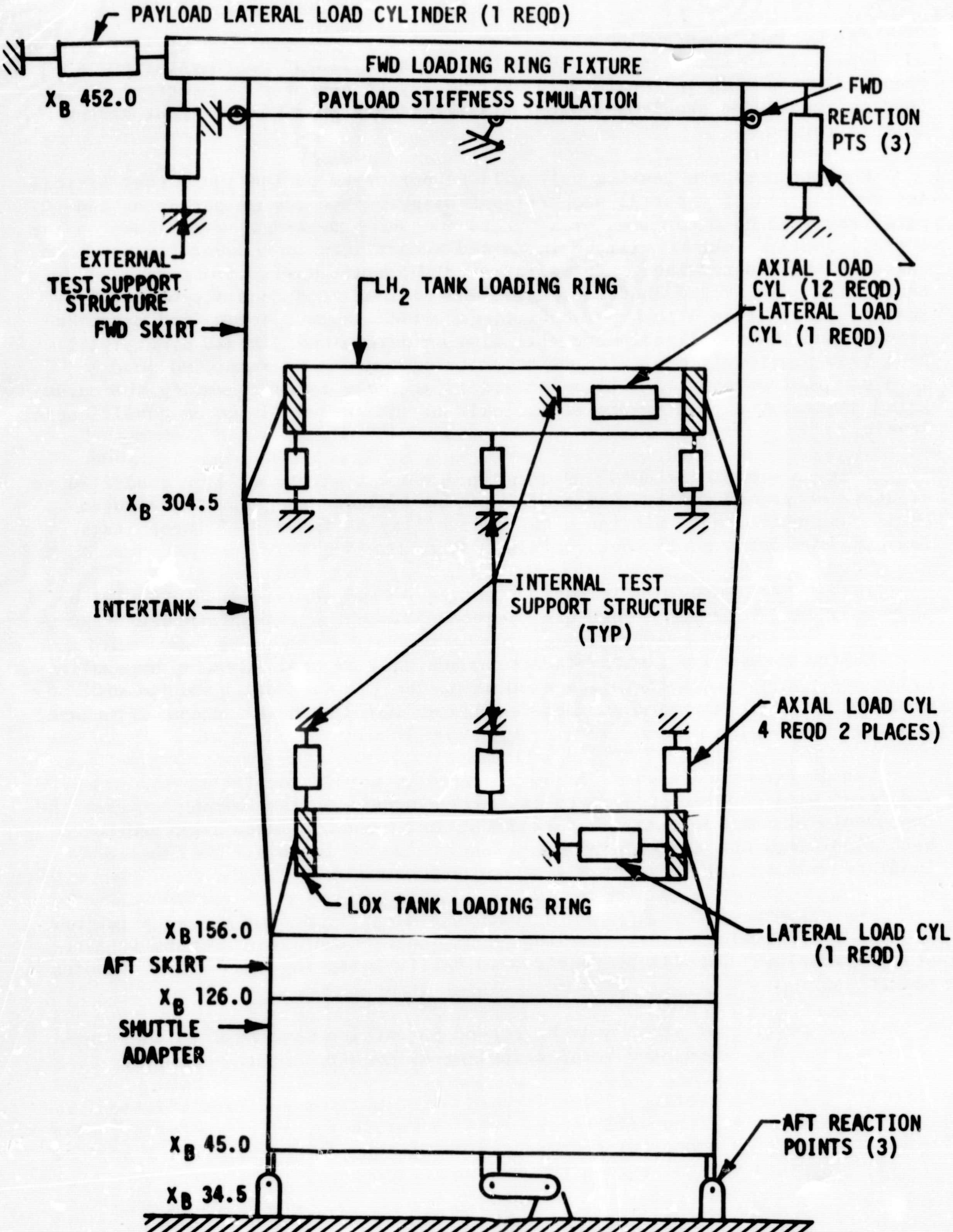


Figure 5.4-1 Outer Shell Test Article

The maximum compression shell test condition consists of a similar loading envelope. As in the tension loading condition, a linear representation is required, this time in the forward skirt. Any excess over theoretical design loading imposes no problems since the skirt is designed for constant strength in this region.

Room temperature testing only will be performed on the shell test article. Any degradation of material properties from predicted design operating temperatures will be determined by separate component testing. Test loads on the overall shell structure will be increased accordingly to account for any degradation so determined. In addition to the basic shell structure, these tests will qualify the shuttle adapter and payload interface attach latches and the six shuttle attach point fittings. Tank support strut load distribution around the shell periphery will also be determined. These struts will have been previously qualified as separate components to predicted load levels. Instrumentation will be provided for these tests to verify the calculated distribution and ensure strut loads do not exceed the prior qualification levels.

Shuttle capture latches and cargo bay support struts will be qualified as separate component tests. These will not be included as part of the outer shell test specimen to eliminate the possibility of failure of these items damaging the outer shell test article.

<u>Thrust Structure</u>. Verification testing of the thrust structure will be performed on a full scale test article consisting of struts, frames and skin.

Engine thrust and gimbal actuator loads will be applied using hydraulic cylinders. Rigid test fixturing simulating the LOX tank aft bulkhead will be employed to react the applied loads. Figure 5.4-2 shows the thrust structure and test fixture.

Two loading conditions will be required to verify the thrust structure. The first will consist of symmetrical axial thrust and the second includes the components of maximum gimbaled thrust. Gimbal actuator loads required for both conditions are supplied by two actuator load cylinders. No tensile loadings will be required for the thrust structure.

These tests will verify the structural integrity of the thrust structure under the critical stability loading conditions. Separate component testing of individual struts will be required to verify integrity under the following conditions:

1. A portion of strut must be loaded in axial compression to substantiate the calculated local crippling allowable.

2. Cryogenic testing of the forward strut portion and tank bulkhead attach fittings will be required to verify the strut-to-fitting bond integrity under LOX temperature conditions. Tensile loading will be applied to demonstrate the required capability.

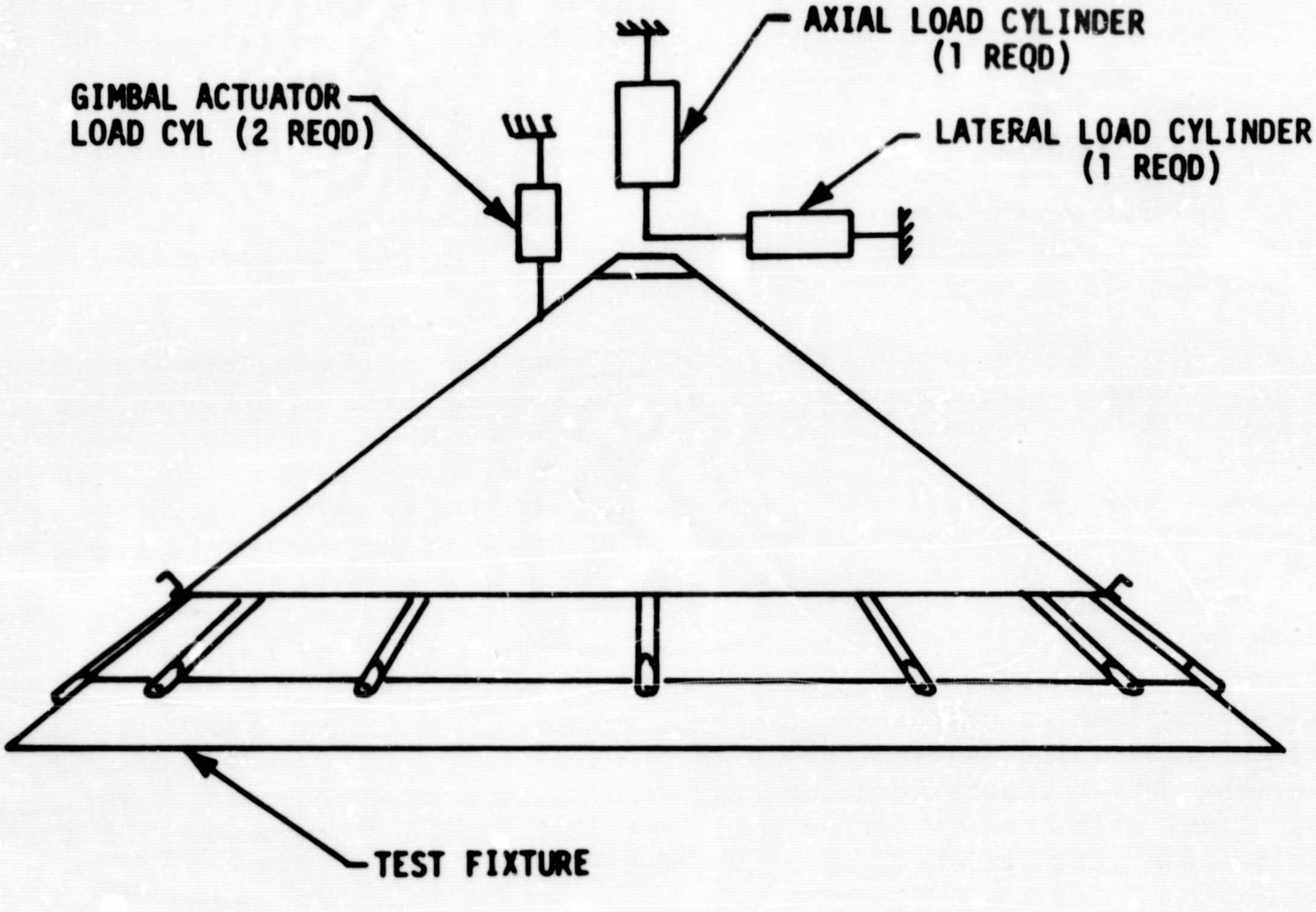


Figure 5.4-2 Thrust Structure Test Article

3. A complete strut must be loaded in axial compression in a fixture capable of duplicating effects of LOX bulkhead deflections and rotations on the forward attach fitting. Column node points will be forced by springs representative of the radial stiffnesses of the two stability frames. The aft fitting will be fixed to represent strut attachment to the thrust block.

LH_2 Tank. Structural verification of the LH_2 tank structure, LH_2 tank to composite truss joint and composite truss to outer shell joint will be accomplished as shown in Figure 5.4-3.

As shown, the LH_2 tank will be filled with LH_2 to design levels and pressurized to ultimate design pressure at point ① in order to simulate maximum loading during the End Burn (Orbiter Thrust) condition. Also, the tank will be partially filled and pressurized to ultimate pressure levels to simulate shell loadings and temperatures which occur during the Space TUG operation phase of the mission cycle.

Structural verification of the LH_2 tank to composite truss joint will be accomplished by partially filling the LH_2 tank with LN_2 to simulate the maximum "g" loading which occurs during the End Burn condition. The tank will be pressurized to match this design pressure at point ② as shown in Figure 5.4-3.

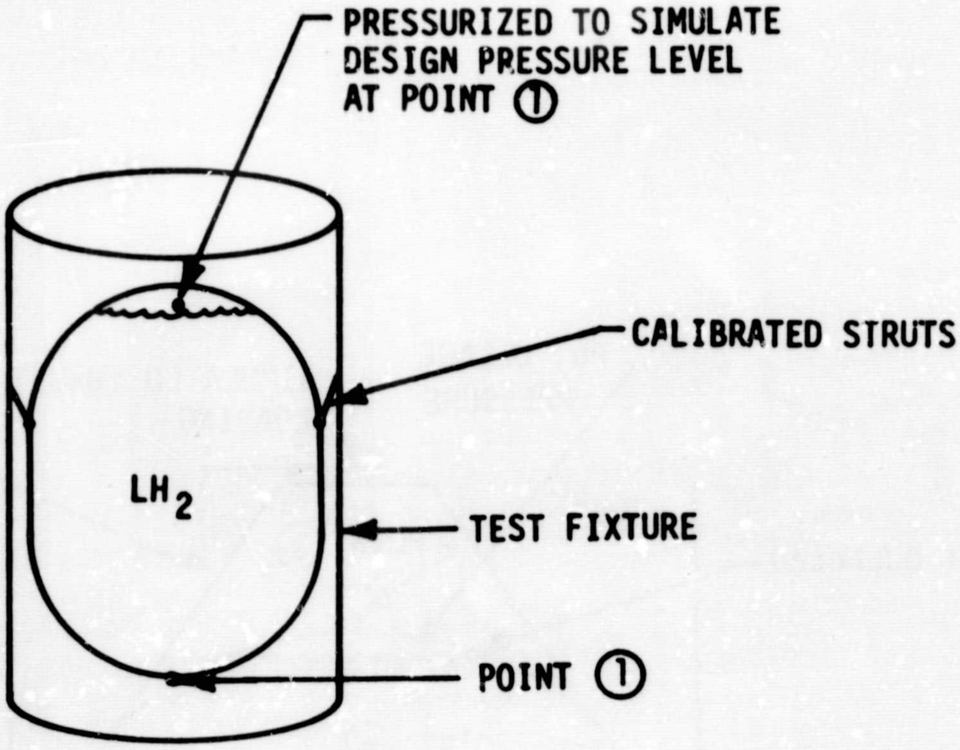
LOX Tank. Subsequent to the foregoing component and complete structural testing, a thrust structure test article will be employed in verification testing of the LOX tank.

Structural verification of the LOX tank structure, thrust structure to aft bulkhead joint, LOX tank to composite truss joint and composite truss to outer shell joint will be accomplished as shown in Figure 5.4-4.

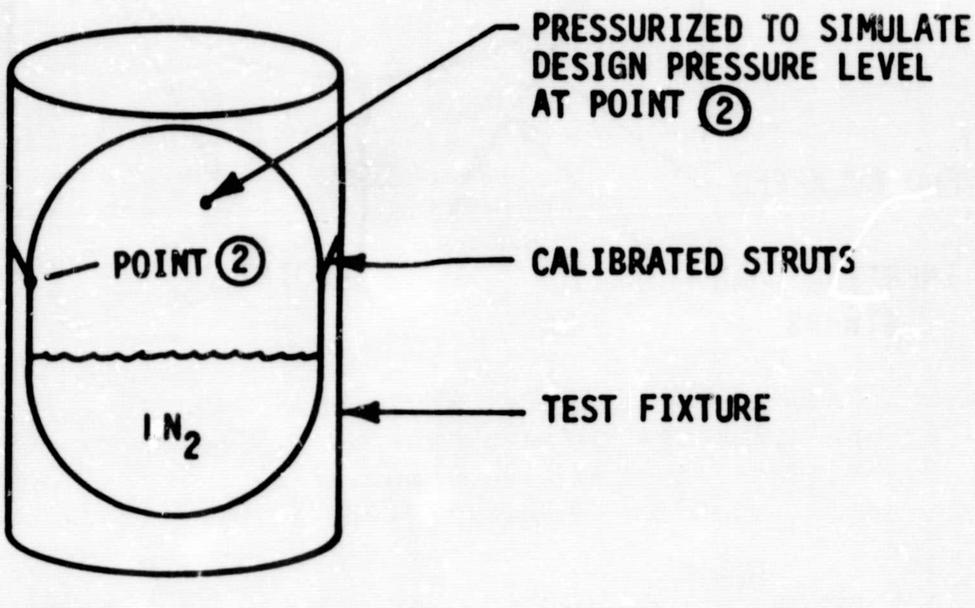
The LOX tank will be filled with LN_2 and pressurized to achieve the design pressure level at point ① in order to simulate the End Burn condition. This requires overloading of the structure at points ② and ③. However, the extra material which is required in these areas for the fracture mechanics assessment (crack growth requirements) will allow such overloading. The stress level at point ① during this test will be about ten percent (10%) less than the ultimate strength of the material.

Also, the tank will be partially filled with LN_2 and pressurized to ultimate pressure levels to simulate the design shell loadings and temperatures during the TUG operation phase of the mission cycle.

Structural verification of the thrust structure to aft bulkhead joint will be accomplished by applying simulated design thrust loading in conjunction with design minimum and ultimate tank pressures at point ④.



(LH_2 TANK STRUCTURAL VERIFICATION)



(LH_2 TANK TO COMPOSITE TRUSS JOINT/OUTER SHELL JOINT STRUCTURAL VERIFICATION)

Figure 5.4-3 LH_2 Tank Test Article

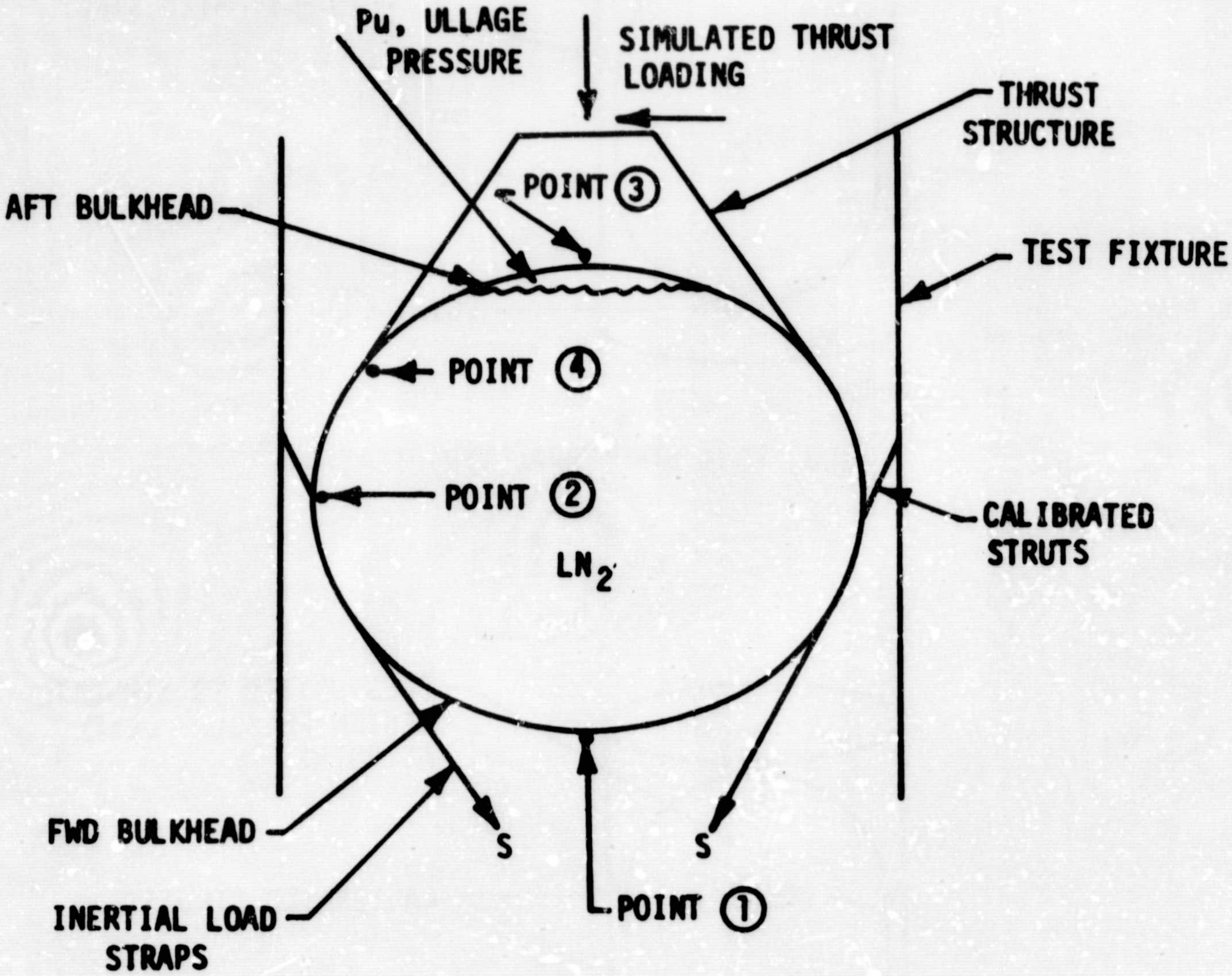


Figure 5.4-4 LOX Tank Test Article

In order to simulate the maximum hoop compressive loading in the equatorial region of the forward bulkhead, which occurs during the End Burn condition, the tank will be pressurized to simulate minimum tank pressure at point ② and strap loads will be applied to simulate maximum inertial loading.

The tank will be pressurized to simulate design ultimate pressure at point ② and strap loads will be applied to simulate the maximum inertial loading of the design condition. This test will verify the tank to composite truss joint.

Dynamic. Dynamic testing will include scaled model testing, component testing, vibroacoustic testing, POGO testing and flight verification testing. In addition, functional development tests of the docking system are required.

Scaled model testing will be performed to determine structural responses of the Space TUG in the Earth Orbital Shuttle (EOS) cargo bay to inputs from the EOS support structure. This model testing will be performed early in the development phase to verify the lower modes and loads criteria.

Component dynamic testing will be performed on individual components with mounting brackets included. Environmental criteria will be initially determined by applying state-of-the-art prediction techniques. A trade-off study will be made to identify those components which should be tested individually and those which may be tested in a vibroacoustic test setup in combination with the other components. This will be dependent upon technical feasibility, costs and schedule impact. In assessing the technical feasibility, it will be necessary to evaluate the energy which may be induced below about 50 Hz by acoustic excitation as compared to the inputs mechanically induced at the EOS/TUG interface. It will also be necessary to consider the anticipated low frequency response characteristics of the component. If the item is considered sensitive to frequencies below about 50 Hz and the acoustic energy is insufficient to excite it properly, it will be required to test these components individually.

The feasibility of utilizing vibroacoustic testing to verify vibration environments was demonstrated on the Saturn S-II Program. Several major subassemblies of the Saturn S-II with dummy masses to simulate components were subjected to vibroacoustic testing.

The results when compared to flight data showed that this was a realistic method to simulate flight conditions. Therefore, for the Space TUG Program, it is planned as early as possible to perform vibroacoustic tests with simulated components to verify design criteria and support bracketry. This same test bed will then be used to mount actual components for qualification testing. For the purpose of obtaining structural response characteristics, due to acoustic excitation, it will not be required to include tank insulation in the fabrication of the test specimens.

It is planned to use refurbished static test articles for the vibroacoustic tests. There will be two vibroacoustic test specimens:

1. A forward skirt section about eight feet long with actual or simulated flight components installed.

2. Thrust structure, LOX tank, EOS adapter, simulated engine mass, feedlines, and the body shell extending above the LOX tank, with actual or simulated flight components installed. The LOX tank may be simulated if the schedule demands, however, the flight LOX tank must be installed for the POGO tests described below. An acoustic closure is required above the LOX tank.

POGO vibration testing will be accomplished utilizing the vibroacoustic test specimen with a flight LOX tank installed. These tests will be conducted at various liquid (water) levels to determine the bulkhead frequencies, mode shapes, and pressure distributions. A sensitivity study will be made to determine whether the LH_2 tank will have to be tested in order to define the same parameters as for the LOX tank. It is planned to obtain feedline flow characteristics including the pump cavitation compliance and dynamic gain during the propulsion development tests conducted by the engine contractor.

The flight test vehicle will be instrumented with sufficient accelerometers and microphones to verify environmental conditions. The TUG responses due to EOS inputs will also be determined from the flight data.

The docking system will require functional development tests to determine an adequate design, followed by structural tests to verify integrity. The docking mechanisms will be mounted on a structure which simulates the vehicle mass and inertia. The docking system design must accommodate the desired docking situations with high reliability and low probability of damage.

5.4.4 Battleship Test Program

A battleship test article has been proposed for support of both design development and verification requirements. A battleship test program will afford a better continuity between the pure laboratory development activities and the design verification phase on a flight test vehicle. Dedication of a flight configured test article in the program development phase also affords an earlier opportunity to evaluate many of the proposed flight components and subsystems in a combined or integrated systems operational mode. The battleship test article will be fabricated to the planned flight configuration designs with the exception of heavier gauge material for the propellant tanks and aluminum or steel substituted for the outer shell. This approach has been selected to allow for greater margins of safety to operating personnel and to the test article and further permits the validation of systems margins through limit design testing. Propellant tank insulation will consist of spray-on foam rather than the flight configuration multiple layer insulation (MLI). This decision has been made due to the better insulating properties of spray-on foam at earth atmosphere environments.

The objectives of the battleship test program will be to supply design information, demonstrate system adequacy and determine system performance under simulated operational conditions. In achieving these objectives, the test program will involve a phased evolution of installed components and systems and the corresponding test category. Initially, the test program will be supported by engineering development hardware on a subsystems basis and will culminate with flight prototype hardware being installed to support combined and integrated systems testing. The battleship test program will be utilized to support the following general requirements:

1. Obtain empirical data and calibration coefficients early in the development phase and thereby assist in attaining an efficient final design selection.

2. Validate the performance parameters and integrity of the final design.

3. Develop and verify operational techniques.

4. Validate design margins through peripheral off-limits testing.

5. Identify performance variations and functional interactions within design limits.

In addition to individual component/subsystems evaluation testing, combined and integrated systems tests will also be conducted in support of the following specific program objectives:

1. Develop and demonstrate the pressurization and propellant feed systems compatibility to engine systems overall operational requirements.

2. Establish engine reference control settings, response rates, pressure flows and temperature levels for each operation mode requirement of a mission phase. These operating modes will represent the typical modes expected in a normal mission phase: pre-start, pre-pressurization, chill idle, pumped idle, pumped mainstage, cutoff, coast and restart.

3. Establish overall systems fluid, propellant and pressure flows and operating temperatures.

4. Verify the accuracy and methods of obtaining calibration coefficients.

5. Establish blow-down times and pressurization times for the propellant tanks.

6. Verify the capability of the inerting and venting system to reduce the concentration levels of GOX and GH_2 in the propellant tanks.

7. Verify the capability of the pressurization system to maintain normal propellant tank pressures during engine mainstage.

8. Demonstrate the compatibility between the engine and the stage pressurization system, e.g., the engine LOX heat exchanger.

9. Verify APS performance parameters, such as flow rates, operating temperatures and pressures.

10. Demonstrate the compatibility between the avionics subsystems and the mechanical systems.

    a. Instrumentation sampling rates.

    b. DMS control and monitoring capabilities.

    c. EPS consumables rate reduction and stabilization capabilities.

Cryogenics cold flow and engine static firing tests will be conducted to evaluate system performance parameters and for verification of operational procedures. The battleship test article will also be used to support the following activities: a) software development; b) servicing, handling and operational procedures development; and c) support equipment development and interface verification.

5.4.5 Computer Software

The identification of Space TUG testing, GSE configuration, software functional requirements, and the approach and rationale to testing is dependent upon the degree to which computer controlled equipment is utilized. Concepts described will serve as a basis around which the software testing concepts will be developed. The automatic testing approach is conceptually visualized as consisting of three major phases: 1) software concepts and approach; 2) software development for space vehicle/ground support equipment (GSE); and 3) software development for data processing.

The objective in establishing an early test configuration will be to define command computer equipment facilities and system software requirements to support Space TUG and ground support equipment (GSE) testing. Subsequent to establishing the configuration of computing facilities, software development and testing activities commence. The testing performed against a particular computer program will be based upon a realistic, cost-effective assessment of the test environment, program type, and the requirement that the program perform error-free. A Computer Program Development Facility (CPDF) will be utilized for software development and testing. The software will encompass the following: semi-operator control of test; provisioning for recycling to a safe or restart point-overriding a malfunction or skipping; safeguards; and a permanent record of operator actions taken. De-bugging aids, including program status display on command, the capability of making alterations in programs and the ability to sequence with display will also be developed.

Software testing will be conducted at CPDF to a level that is the most cost-effective. Logical decision-making based on flags, measured responses, etc., will be tested utilizing a go/no-go simulation mode. Program interfaces with executive routines and logical branching options will also be tested. De-bugging, such as traces, dumps, etc., although oriented toward off-line use, will also be available for real-time de-bugging and testing aids.

Space TUG Testing

Software will be required to support the Space TUG subsystem/systems and the ground support equipment self test. Software development to support Space TUG testing will begin at the subsystem level. At this test level, the programs are comprehensive and are directed toward the individual subsystems. The next level of testing will be the integrated subsystem level. These programs are broad in scope and are of less detail. An overall Space TUG system level test is conducted next. This test is conducted at two levels; simulated flight of the integrated system with umbilicals and simulated flight of the integrated system without umbilicals.

Testing at both the subsystem and system level will utilize the capability of the on-board computer to minimize support equipment software requirements. Software programs will be utilized for the functional verification of GSE. These programs will support both the GSE subsystems and integrated systems level testing. A Ground Support Equipment Test Set (GSETS) will be utilized for support of the GSE integrated system verification.

The GSETS is employed as a substitute for the Space TUG, for the purpose of verifying the functional readiness of the GSE prior to interfacing with the Space TUG. The GSETS will be capable of receiving hardwire stimuli and by using proper patching and switching will be able to simulate Space TUG responses to the GSE. Software programs will also be utilized for the functional verification of individual items of Ground Support Equipment (GSE) that contain automatic checkout capabilities.

A series of computer programs that will exercise the automatic capabilities will be provided; errors are detected by manual and/or computer comparison of responses received to the expected.

Data Reduction Programs

Methods of expediting analysis of test-derived data are necessary to support testing. These methods consist of a system of data retrieval and reduction programs and associated reference files. These programs provide software systems to expedite accurately the data reduction and evaluation process and at the same time provide the most reliable indicator of proper system/subsystem operation. Data reduction software systems will be designed to standardize the development, maintenance, and documentation of programs

and data files contained within it. Programs will be developed as the need arises to expand or improve existing systems or as the need for improved data processing systems are indicated.

5.5 QUALIFICATION TESTING

Qualification tests are conducted to verify functional performance and confirm design compliance. Qualification tests include functional performance, static/dynamic, and other environmental testing to ensure effective performance during a mission.

Since the Space TUG is based on a high mass fraction design, many of the systems which normally require redundancies for increased mission success probability will be eliminated. To provide confidence in production hardware and minimize cost, qualification testing will be accomplished through an integrated program utilizing hardware analysis and selected qualification testing.

5.5.1 Qualification Testing Criteria

The following criteria will be used to determine component qualification testing:

1. Qualification requirements will be satisfied by analysis or test or a combination of both. The analysis will be in the form of past test history, component subassembly wear analysis, development test data analysis and other pertinent analysis criteria. Testing will be in the form of selected qualification test, additional development test or a more rigorous acceptance test requirement.

2. Qualification by test of components will be based on the functional criticality of the subsystem and all components which through failure could result in loss of crew or vehicle (criticality I and/or II). Where redundancy has eliminated a critical single point failure, both redundant hardware will be qualified as though no redundancy existed.

3. Qualification testing will be accomplished at the highest practical level of assembly.

4. Qualification test levels will encompass static and dynamic environments resulting from Space TUG storage, transportation, boost, orbit, mission, and reentry and return to earth and will include safety margins. The test levels will not exceed specification levels, therefore allowing reuse of hardware for other ground test programs.

5. Mission life tests will be based on a maintenance cycle, or multiples thereof. Some components mission life tests will be based on total life expectancy.

6. All qualification test specimens will be production hardware (same as flight hardware) which have been acceptance tested prior to qualification testing.

7. Test sequence during qualification testing will follow the order in which the environment will be encountered by the flight hardware when practicable.

8. Hardware requalification will be required when (1) design or manufacturing processes are changed to the extent of invalidating the original qualification or development test, (2) the manufacturing source is changed, or (3) when more severe environments or operational conditions exist.

9. Qualification testing facilities will be surveyed for testing capability and adequacy of instrumentation.

5.5.2 Components

Achieving qualification on the component level requires an integrated analysis and test program. This approach is necessary since many components will be qualified by analysis. The following criteria will form the basic approach to qualification:

1. All component design will be reviewed from initial design concepts to ensure utilization of long life technology, simplicity of design and adequate design margins. This analysis will generate component subassembly development testing recommendations.

2. A pretest analysis will be performed on all mechanical and electrical components. The pretest analysis will provide a detailed description of the component, its use, the design limits and tolerances, mounting methods, static and dynamic requirements, environmental requirements, mission requirements and recommendations. This information will be utilized to recommend selected development tests, to select components for qualification testing, to designate degree of qualification testing and to determine the best testing approach.

3. Vendor and in-house production procedure will be evaluated and monitored to ensure that production controls, utilized during the qualification test specimen buildup, are maintained.

4. Test procedures and test equipment utilized for testing at subcontractors and suppliers will be standardized.

5. Component qualification requirement lists will be established to indicate the method of qualification.

5.5.3 Systems

TUG systems will be qualified in a similar manner as component qualification, using a combination of analysis and/or tests. A systems pretest analysis will be performed to judiciously select systems requiring qualification by test. The test used in qualifying the systems will consist of subjecting representative specimens to a preselected combination of environmental and functional operations to simulate the most severe conditions which will be experienced in performing a baseline mission. Mission life tests and test duration will be based on the Space TUG maintenance cycle. Statements of system performance, output parameters and out of tolerance problems will be made on the basis of data obtained. The design of the systems tests also provides information regarding the functional effects of the environments to which the system is exposed.

The data accumulated during this test program will be correlated with the data accumulated during component qualification to achieve systems qualification.

5.6 DESIGN VERIFICATION

Design verification testing is concerned with engineering evaluation of hardware and software at the subsystem, systems, and integrated system level for the purpose of acquiring engineering data, evaluating overall configuration performance and providing the necessary confidence that the system will meet the specification requirements.

Design verification testing will be conducted on the battleship test article and flight test vehicle and consists of: 1) cold flow; 2) thermal vacuum; 3) electromagnetic compatibility; 4) electromagnetic interference; and 5) static firing tests.

5.6.1 Static Firing

A static firing test program will be conducted on the flight test vehicle in support of the design verification test plan. Vehicle systems compatibility, component integrity and operational procedures verification will be the major goals for this test program.

Pre- and post-static firing integrated systems evaluation data will be compared for assessment of any possible systems degradation resulting from cryogenic cycling/engine operation induced vibrations. Additionally, static firing data will be utilized as supplemental data to the Battleship Test Program for support of engine reliability requirements. Dwell time of the flight test vehicle at the static firing facility is contingent upon vehicle/facility problems associated with first usage, procedures refinements, personnel training programs, and required static firing cycles.

5.6.2 Thermal Vacuum

The purpose of the thermal vacuum test is to demonstrate long term Space TUG functional performance while operating in a simulated space environment.

The test program will be designed to support the requirements of design verification and to develop response characteristics and operational procedures for use in acceptance testing. Design verification requirements dictate a chamber altitude pressure level of at least 10^{-4} Torr. Consequently, the flight test vehicle will be transported to the thermal vacuum facility (Chamber A) at MSC subsequent to the static fire test program at MSFC. Typical of the thermal control conditions to be investigated are:

1. Temperature during parking orbit; the combination of earth emission, earth albedo and solar environment.

2. Temperature during mid-course correction; the combination propulsion burn temperature, plus random solar heating.

3. Temperature during space soak, cruise and geosynchronous orbit operations.

Upon completion of the design verification series, at an altitude level of 10^{-4} Torr, the flight test vehicle will be subjected to an additional test cycle to an altitude level of 10^{-2} Torr. This latter cycle will be utilized as a performance reference for a performance calibration cross-check in the Kennedy Space Center (KSC) thermo-vacuum facility. The KSC chamber has an evacuation capability, limited to 10^{-2} Torr. Subsequent vehicles (operational) will be shipped directly to KSC for thermo-vacuum acceptance testing at the 10^{-2} Torr level. Satisfactory performance of the integrated systems in a simulated flight mode will be considered sufficient qualification of the vehicle for thermo-vacuum acceptance. Additionally, confidence in the MLI installation processes during vehicle assembly will have been proven.

An integrated system test will be conducted prior to commitment of the flight test vehicle to the thermal vacuum test program. Subsequent to thermal vacuum testing and evaluation, integrated system tests will be rerun as post-environmental checks for system degradation.

5.6.3 Electromagnetic Compatibility

An electromagnetic compatibility (EMC) test will be performed to detect and isolate any electromagnetically induced disturbances that would cause undesirable functioning of the Space TUG systems and obtain electromagnetic signature during the operational modes of the Space TUG. The Space TUG will be instrumented by means of breakout boxes (threshold detectors) and portable recorders. A complete functional electromagnetic compatibility test will be conducted utilizing flight system checkout programs and techniques. Typical circuits to be monitored are the on-board receivers (for spurious interrogation), main electrical power buses (for transients), and trigger signals to engine firing circuits.

5.6.4 Electromagnetic Interference

The object of the electromagnetic interference (EMI) test is to evaluate Space TUG systems in the presence of the normal operational radio frequencies and field strengths known to exist at the launch site and to determine the

effects of Space TUG operating modes upon the on-board radio (command) receivers. The EMI tests encompass: 1) spurious emanation tests; 2) radio command receiver input tests; and 3) the Space TUG radio frequency (radiation) survey. The spurious emanation tests consist of hardline monitoring of the unmodulated output of Space TUG transmitters for possible presence of spurious RF signals. The radio receiver input tests involve hardline monitoring of the input to the command receivers from Space TUG system generated spurious emission while the on-board transmitters are transmitting modulated signals. The radiation survey consists of monitoring and recording the frequencies and levels of radiated energy while on-board transmitters are sending modulated signals through on-board antennae.

5.6.5 Flight Test

Flight testing of the Space TUG, its components or subsystems, will be accomplished in concert with the operational Earth Orbiter Shuttle vehicle. The flight test program will be conducted to support the design verification test plan. Orbital tests of the Space TUG flight test vehicle will be used to verify subsystem performance, thermal control and insulation suitability, propulsion system zero-g flow/transfer capability, and deployment/retrieval operations.

5.7 ACCEPTANCE AND FLIGHT TEST

Acceptance tests are defined as those tests conducted on deliverable flight and support equipment to demonstrate that the product complies with specifications, is free from defects, and is capable of performing in conformance with stated contractual requirements. Acceptance tests begin with suppliers' test and continue through demonstration at the time of the Space TUG vehicle delivery and acceptance by the customer.

Acceptance checkout criteria is as follows:

1. Acceptance tests at the component/subassembly level will provide the necessary quality/inspection and testing controls to assure that pre-installation testing will not be required.

2. Subsystem level tests will include a demonstration of alternate and/or redundant modes of operation (where applicable), by exercising sub-routines compatible with the on-board computer capability.

3. All deliverable end-items will be subjected to an acceptance checkout.

4. The on-board checkout capability in conjunction with post-manufacturing functional tests, will be used for acceptance testing as applicable.

5. Repetitive acceptance testing will be minimized throughout the cycle, from manufacturing to launch.

6. For environmental sensitive hardware, acceptance tests at the component/subassembly level will include specific environmental tests at a level commensurate with mission requirements, or to screen defects whichever is greater. Criteria for selection of components and environments will be similar to those used on previous programs where proven effective.

7. Electromagnetic emission and/or susceptibility will be determined at the subassembly (black box), subsystems, and vehicle level.

8. Acceptance of supplier equipment shall take place at the manufacturing source, insofar as is practical.

9. Components or subassemblies either built by the prime end-item contractor, or not source inspected and accepted, shall be subject to the same acceptance requirements specified for vendor acceptance testing.

10. Each measured parameter designated for acceptance testing shall have a specified tolerance band of acceptability and nominal value.

11. End-item ground support equipment shall be accepted by a functional test according to specification. Where appropriate, the first article of an end-item model shall have an environmental acceptance test tailored to its expected "in-use" external environment under worst case conditions. The test will be for a duration sufficient to disclose functional/environmental exposure deficiencies.

13. Excessive shelf-life prior to installation may require a partial or complete acceptance retest for those items designated age-sensitive or delicate. These items will have the maximum handling requirements or shelf-life before retest specified in appropriate Engineering documentation.

14. An integrated checkout of the flight vehicle shall be conducted subsequent to final assembly. This checkout will confirm that the vehicle has been manufactured and tested in accordance with Engineering documentation and approved shop practices.

15. Operational site interface testing shall verify the various vehicle interface requirements, including separation, communication and data functions, and integrated vehicle pneumatic, propellant, purge, and power compatibility with ground support equipment and launch facilities.

16. System/subsystem performance evaluation (while installed on or in the flight vehicle) shall utilize operational (natural) signals as stimuli insofar as possible.

17. Retest may be required whenever:

    a. The test was not performed in accordance with approved specification or procedure..

    b. Test equipment malfunctions or operator errors occur.

    c. Modifications, repairs, replacement, or rework of the article or material occur after completion of testing. Retest will normally be restricted to the effected article or disturbed systems.

    d. Periodic intervals for retest shall be established on articles or materials subject to drift or degradation due to storage or handling.

    e. The number of retests shall be limited and based on the limited life of the equipment.

18. GFE (government-furnished equipment) used to support and/or perform tests will be controlled by the contractor. GFE maintenance or calibration will be accomplished utilizing government furnished base support services. GFE that becomes part of deliverable end-item hardware will be tested and controlled as part of that end-item.

5.7.1 Acceptance

Post-Manufacturing Checkout (PMC)

Post-manufacturing acceptance tests, conducted subsequent to completion of systems installation, verify the operational compatibility of integrated subsystems and applicable ground support equipment. Prior to start of Space TUG checkout operations, the support equipment and facilities will be integrated to form the system test complex in preparation for safely interfacing with the Space TUG vehicle. Post-manufacturing checkout operations will be conducted with ground power sources and under ambient conditions.

System Test

An integrated subsystem test program will be utilized for subsystem/system design verification. In addition, ground support equipment (GSE), test procedures, software and techniques will also be verified. The flight test program is directed toward the verification and integration of flight vehicle subsystems and to assure compatibility and absence of untoward interactions.

The Space TUG major test discipline is divided into two areas: 1) propulsion (mechanical, and 2) avionics (electrical). These test disciplines are structured into the following subsystems:

Propulsion

1. Propellant feed, fill and drain

2. Safing and venting

3. Propellant management

4. Pressurization

5. Reaction control

6. Main propulsion

7. Thrust vector control

8. Fuel cell

Avionics

1. Data Management Subsystem (DMS)

   a. Computer

   b. Data Acquisition Units (DAU)

   c. Interface Units (IU)

   d. Measurement Processor Unit (MPU)

   e. Status and Control Panel (S&CP)

2. Communication Subsystems

   a. Antennae

   b. Radio Frequency Subsystem

      [1] Transmitter

      [2] Transponder

   c. Baseband Subsystem

      [1] Bi-phase modulator

      [2] Command decoder

3. Guidance, Navigation and Control (GN&C)

    a. Inertial Measurement Unit (IMU)

    b. Star tracker

    c. Horizon tracker

    d. Autocollimator

    e. Laser radar

    f. Television

    g. Backup stabilization assembly

4. Power Conversion and Distribution

    a. Fuel cell

    b. Backup battery system

    c. Fuel cell control unit

    d. Power control switching

5. Instrumentation Subsystem

The conduct of the Integrated Subsystem Test Program begins with the pretest readiness tests and/or checks that establish preliminary conditions, and progress through a series of functional readiness tests and culminate in the subsystem/system functional test. Subsystem level tests are designed as a comprehensive exercise and verification of system performance through all phases and modes, including, where applicable, backup modes. These tests provide baseline data, in standard configuration, for comparison from test to test, from ambient to environmental, and from test to mission. The on-board statusing and checkout capability in conjunction with ground support equipment will be used to perform installed system level testing.

Subsequent to the subsystem and combined subsystems test, a simulated flight of integrated systems is performed. This test consists of all the subsystems of the Space TUG in their flight configuration, including cabling and interface connections. The general sequence of testing is to perform readiness checks which include power and measurement checks, instrumentation checks and verification of both electrical and mechanical systems. A controlled terminal countdown will be conducted in real time prior to the simulated flights. This countdown duplicates, within ambient temperature limitations, the preparations that are required for actual flight at the launch site. Alternate modes of simulated flight will be conducted. A simulated launch operations will be performed which will culminate with a demonstration of Space TUG operations during EOS flight abort. This test will be performed with Space TUG umbilical connectors configurated to duplicate EOS interfaces.

A second simulated flight will be performed with Space TUG/EOS umbilicals connected to verify Space TUG performance under conditions that are as close to flight as possible, and limited only by the test environment. The test will duplicate the Space TUG readiness checks required prior to commitment of the Space TUG to its mission. Subsequent to Space TUG mission commitment, a simulated flight with umbilicals disconnected will be conducted. A mission to geosynchronous orbit will be simulated including rendezvous maneuvers, simulated payload disconnect and connect. Space TUG/orbiter rendezvous will be simulated to verify Space TUG maneuvers, safing and purging, umbilical interfacing, and reconfiguration for orbiter descent. The simulated flight test program is mission event sequence oriented and test implementation is conducted by time compression of time line segments.

Electromagnetic Compatibility Tests

During the conduct of an integrated systems functional checkout, critical commands and performance responses will be monitored. The vehicle will be instrumented by means of breakout boxes and oscillograph recorders to obtain a time history recording of the selected parameters. Recorded data will be reviewed in a post-test analysis to verify signal levels are within specification. In addition, each parameter will be critically reviewed to verify that no adverse cross coupling (electromagnetic induction) exists. Spurious responses and transients will be evaluated for threshold level acceptability.

Guidance, Navigation and Control Alignment

An alignment of the guidance, navigation and control instruments will be performed. During alignment/calibration, the line-of-sight of rendezvous and docking instruments will be measured to each other and to a reference plane on the Space TUG structure. Engine attach pad, gimbal actuator alignment, and telemetry verification tests will be performed to: 1) determine optically and mechanically the thrust axis (geometric center line of engine nozzle) relative to Space TUG reference surfaces; and 2) to verify pre-aim points, maximum actuator travel, and telemetry data calibration accuracy.

Weight and Center of Gravity Measurements

The weight and center of gravity (CG) measurement will be performed to accurately determine the actual weight and CG of the Space TUG. Determination of actual weight and CG provides a baseline reference for evaluation of actual and calculated design parameters. This test is conducted subsequent to system functional testing.

5.7.2 Flight Test

Flight testing includes those flight tests required to determine the compatibility, functional, and operational suitability of the Space TUG systems. Compatibility of the Space TUG with prelaunch operations of the Shuttle vehicle will also be verified. After launch and orbital injection,

the Space TUG undergoes a series of in-flight operations designed to certify the Space TUG for its assigned missions. Under present program concepts, the flight test vehicle will be the first all flight configured vehicle scheduled for fabrication and also serves as the test vehicle for the verification of planned in-line operations, testing, processing and handling. Subsequent to its normal ground test program flow, the first flight vehicle will be committed to the flight operations test program. Only one flight test vehicle is presently anticipated. The second (operational) vehicle scheduled for production may be used as a backup flight test vehicle in the event the first flight test vehicle is damaged or expended. In this event, assessment of remaining objectives will have to be weighed against possible impact to planned operational mission scheduling or effect on overall master program scheduling.

Ground Operations

This section describes the proposed launch site test flow and objectives. The initial phase involving the flight test vehicle, is utilized to evaluate procedures demonstrating the Space TUG vehicle compatibility with launch vehicle and launch site facilities. Flight vehicle launch site operations are: 1) verify the Space TUG post-shipment condition; 2) demonstrate compatibility of Space TUG with launch vehicle and complex; and 3) verify operational procedures and techniques. The initial operations start with the arrival of the Space TUG during which the Space TUG is inspected and readied for conduct of non-hazardous operations. The facility and test complex will be checked out and certified ready to safely interface with the Space TUG prior to their operational use. The Space TUG next undergoes system confidence checkout and a thermal vacuum test sequence. Subsequent to Space TUG system and thermal vacuum tests, the Space TUG will be loaded on to the transporter and moved to the EOS test area. The Space TUG operational phase of the test program encompasses those activities to be conducted in conjunction with or in support of the EOS. A launch mode verification test will be conducted with countdown and launch operations following.

The launch site test program consists of two distinct phases: 1) initial phase/confidence checks, and 2) prelaunch and launch phase. For the initial phase, the test sequence will be designed to evaluate the procedures, train personnel and demonstrate Space TUG and ground support equipment compatibility to launch complex. Second phase operations will be limited to activities required to prepare the Space TUG for launch and launch operations.

Space TUG Arrival at Launch Site

The Space TUG, upon arrival, will be unloaded, inspected, and made ready for system tests. The Space TUG will be completely inspected visually to verify that no damage was incurred in shipment and the environmental data recorded during transportation are reviewed to determine that the vehicle was not exposed to any adverse environments.

Preparation. Subsequent to post-shipment inspection, preparations will be performed to configure the Space TUG for electrical/mechanical system tests and perform all non-hazardous preparations possible before movement to the test area.

Post-Shipment System Tests. Post-shipment tests will be conducted to provide final verification that the Space TUG and its subsystems meet all their functional requirements. These tests are similar to those tests performed during post-manufacturing checkout. The data obtained as a result of the test effort will be compared with the results of previous tests to verify acceptance of the Space TUG. The final calibration of rendezvous instruments will be performed to provide for assessment of the effects of time and environment on the Space TUG systems in order to ensure effects have not compromised vehicle capabilities. Functional test and calibration activities will be normally restricted to activities that can be performed without removal of flight hardware or the demating of flight connectors. Subsequent to the completion of the functional verification tests, the Space TUG configuration will be controlled to ensure that no activity is initiated that would invalidate the continuity of the test program.

Installation of Mating Mechanism. The Space TUG-payload adapter and docking mechanism will be installed. Subsequent to installation, the operation of the latching-unlatching mechanical docking system will be verified. The objective of this test is to verify the compatibility of the Space TUG-docking mechanism-payload interface.

Space Network Interface Test. A series of tests will be performed to verify the Space TUG communication compatibility with the Manned Space Flight Network (MSFN). The object of this series of tests will be to demonstrate functional and operational compatibility among all interfacing elements required for Space TUG mission support. These tests will be conducted between the Space TUG and the compatibility test area (CTA). These tests establish the degree to which the telecommunication portion of the Space TUG/Space Networks meet the requirements imposed during a Space TUG mission. These tests will also verify the operational readiness of the support elements required for mission operations.

Thermal Vacuum Tests. Subsequent to the functional verification tests, the flight test vehicle will be transported to the thermal vacuum chamber to perform space simulation tests. These tests are to be conducted to demonstrate the Space TUG functional performance while operating in a simulated space environment, and to verify the temperature control subsystem's ability to maintain Space TUG temperatures within design limits. The test will be divided into two phases. During Phase 1, the Space TUG will be in a system test configuration with direct-accessible and operating support equipment interfaced or mated to allow maximum evaluation of Space TUG performance. These tests will be designed as a comprehensive exercise and verification of system performance and will include a demonstration of alternate operational modes by exercising subroutines compatible with the on-board computer. Phase 2 testing is similar to Phase 1, except the Space TUG ground support equipment will be held to a minimum. Externally mounted test equipment,

stimuli, test cables, and other non-flight hardware will be removed. This phase allows for an evaluation of the functional performance in an environment similar to that which would be encountered during actual space mission operations. A free mode test will be performed to 1) demonstrate the proper operation of the Space TUG on internal power; 2) verify the functional integrity of the Space TUG in the absence of any extraneous ground support equipment electrical/mechanical connections; and 3) verify that the system test complex and associated cabling did not affect Space TUG system data readout. Performance data monitoring will be accomplished via the telemetry link.

The flight test vehicle will be subjected to a more rigorous thermo-vacuum test program than will be imposed on subsequent operational vehicles. The flight test vehicle will be cycled through the Space Environment Simulation Laboratory at the Manned Space Center, Houston, Texas, in support of the design verification test program (DVT). Subsequent to completion of the test activities required for DVT, at an altitude level of 10^{-4} Torr, the flight test vehicle will undergo a functional verification of integrated systems performance in a simulated flight mode at 10^{-2} Torr. This test sequence data will be utilized as a performance cross check on the Kennedy Space Center (KSC) thermo-vacuum chamber. The purpose of this additional test activity is to preclude the requirement to cycle subsequent (operational) vehicles through the chamber at MSC. Satisfactory performance of the Space TUG integrated systems in a simulated flight mode at the 10^{-2} Torr KSC facility will be utilized as qualification and confidence of the Space TUG systems space flight worthiness.

Post-Thermal Vacuum Tests. A system verification test will be performed to verify that no systems degradation had resulted from the thermal vacuum environment. The verification test is a condensed version of the Space TUG subsystem/system tests with emphasis upon finding faults.

Electromagnetic Interference Test (EMI)

Subsequent to the thermal vacuum test program, the Space TUG will participate with the EOS in a joint evaluation of RF subsystems compatibility. The Space TUG's subsystem's performance responses will be evaluated to verify that no adverse EMI signal levels are induced during normal RF systems operations. Applicable systems performance data will also be reviewed to verify that the RF transmissions do not render performance responses questionable or cause non-programmed stimuli to be issued.

Composite Acceptance Test. A post-environmental test will be conducted to provide final verification that the Space TUG and its subsystem/systems meet their mission functional requirements. The composite acceptance test will be conducted on the end-item flight test vehicle to demonstrate compliance with contractual specifications for customer acceptance. These tests will be similar to tests conducted during the post-manufacturing test program. Test objectives are to demonstrate the subsystem/systems operational compatibility under simulated conditions from initiation of countdown through alternate flight modes and culminating in a simulated rendezvous maneuver.

Space TUG-Payload Interface. The Space TUG payload will be mechanically mated and the docking mechanism operation verified. Subsequent to mating the weight and center-of-gravity (CG) will be measured. This operation will be conducted to accurately determine the actual weight and center-of-gravity of the Space TUG-Payload combination.

Pre-Mate Checkout

The Space TUG will be subjected to a pre-mate checkout to ensure correct functional operation prior to commitment of the Space TUG installation into the cargo bay of the EOS. The pre-mate test is primarily qualitative in nature, and is not intended to provide detailed subsystem information. The prime objective of pre-mate testing will be to demonstrate functional and operational readiness of the Space TUG systems.

Space TUG/EOS Mate

The Space TUG will be installed in the Earth-Orbiter-Shuttle (EOS) cargo bay while the EOS is in the horizontal position. After installation of the Space TUG vehicle, the tie downs and electrical/mechanical interfaces to the EOS will be verified. The flight test vehicle while undergoing operational test activities will be subjected to a more comprehensive and critical review. This review will focus on the verification/development of procedures and techniques for transportation and handling of the vehicle. This review will also serve to verify the facilities operations required for Space TUG installation and handling.

Turnaround Activity Verification

The flight test vehicle will be utilized for verification of the Space TUG maintenance turnaround activity. Normal turnaround activity will verify procedures and techniques to accomplish post-landing safing and securing, including inerting and venting propellant tanks and the purging of tank insulation. The Space TUG vehicle will be removed from the orbiter cargo bay during safing facility verification, loaded on the transporter and moved to the TUG maintenance area. In the maintenance facility, the Space TUG vehicle will be subjected to its normal post-landing activities. The prime objective will be the verification of operational compatibility of procedures, equipment and techniques.

Subsequent to the maintenance turnaround activities, the Space TUG will be transported to the orbiter maintenance area and installed and interfaced into the orbiter cargo bay.

TUG/Launch Vehicle Interface

During the build-up and stacking of the shuttle launch vehicle in the vertical assembly building (VAB), the Space TUG interface will be verified both electrically and mechanically. Included will be the interface verification of the TUG/mobile launch umbilical tower (LUT). These tests are primarily passive but include fit checks, leak checks, and electrical continuity checks.

Launch Pad Operations

The overall objectives of the launch pad operations are: 1) to verify the compatibility of launch complex equipment (LCE) with the Space TUG; 2) to verify the procedures that will be utilized for actual countdown at the launch facility; and 3) to train personnel that will perform the countdown.

Shuttle/LUT/Pad Interface

The objective of the Shuttle/LUT/Pad interface test is the verification of the propellant fill and drain system, including propellant handling facilities. The electrical and mechanical umbilical fit and compatibility will be verified. The verification encompasses the placement of all propellant lines, cables, workstands and protective devices required in support of Space TUG activities.

Space TUG Vertical Removal

The flight test vehicle undergoing operational test activity will be subjected to a comprehensive review to verify and develop procedures and techniques for Space TUG handling while loaded aboard the vertical stacked shuttle vehicle. This review will serve to verify the facility and operations required for Space TUG removal, installation, servicing and handling while on the launch pad.

Launch Readiness

A pre-countdown test will be conducted with participation by all Space TUG launch personnel at their assigned stations. Data and communications between countdown operating stations will be verified and exercised. Concurrently, the launch control equipment will be verified. The on-pad verification test will be performed to verify Space TUG compatibility with the launch environment and provides a final detailed verification of launch readiness. The Space TUG participates in a countdown demonstration with the launch vehicle to verify systems operational compatibility under cryogenic tanking and actual launch operational conditions.

Pre-Launch Servicing

Pre-launch servicing will be performed to condition the space TUG for launch. Servicing includes such items as: 1) pressurizing purge bottles; 2) installation of batteries; 3) verifying hydraulic pressures; 4) securing the Space TUG to flight tensions; and 5) loading of consumables.

Countdown and Launch

The launch countdown will be conducted to condition the Space TUG for launch and to perform Space TUG performance analyses within the bounds of the launch control equipment. The Space TUG will participate in a terminal countdown integrated with the shuttle launch vehicle activities.

Flight Operations

The objectives of the flight operations are: 1) to verify the procedures and operational techniques that will be employed for Shuttle/Space TUG separation, on-orbit operations and rendezvous; 2) to verify compatibility of the Space TUG on-board systems to successfully accomplish a flight mission at the operational environments; 3) to demonstrate the operational compatibility of the flight software; 4) to demonstrate the Space TUG's subsystems capabilities to support the operational phases of a baseline orbital mission; and 5) to validate ground turnaround procedures and techniques. A minimum of four flights will be scheduled to demonstrate and assess the following Space TUG capabilities:

1. Boost and Orbital Phase
    a. Orbital injection
    b. Rendezvous maneuver
    c. Docking
2. Space Events
    a. Establishment of communication links
    b. Guidance and navigation checks
    c. Maneuver capability (RCS)
    d. Stabilization (RCS)
    e. Autonomous operations
    f. On-board checkout
    g. Rendezvous and docking of TUG to payload
    h. Orbital changes (MPS)
    i. Rendezvous and docking of TUG to EOS
    j. TUG orbital safing and purging
    k. Abort mode validations
    l. Consumables budget assessment

The following demonstrations will be accomplished during the earth orbit to geosynchronous orbit flight tests:

1. Geosynchronous injection capability
2. Synchronous orbit transfer capability
3. Pre-planned trajectory capability
4. Transgeosynchronous navigation capability
5. Coast mode
6. Mid-course correction operations
7. Target acquisition operations

In-orbit operations and flight test mission complexity will be phased commensurate to the confidence levels established on preceeding flight test missions. The capability of the Space TUG system to support off-normal operations, e.g., abort and alternate mission mode capability, shall also be demonstrated. Flight test vehicle performance evaluation will be supplemented by monitoring critical performance parameters specially instrumented to support design verification.

Confidence in operational readiness shall be attained after the flight test vehicle has successfully demonstrated its capability of performing a typical baseline design mission. Upon completion of the flight test operations and verification that all test objectives have been satisfactorily completed and all problems resolved, the flight test Space TUG vehicle will be re-assigned to support the operational phase. Depending upon the duration of the flight test phase and types of problems encountered, it may be necessary to accomplish modifications and/or refurbishment of vehicle subsystems prior to assuming its role in the operational phase.

The Flight Test Vehicle Test Program, shown in Figure 5.7-1, outlines the major test activities planned for the Flight Test Vehicle.

5.8 TEST SCHEDULES

The preliminary test development schedule, Figure 5.8-1 shows the major program milestones and activities necessary for the design, development, production, and test of the flight test Space TUG. The schedule is based on manufacturing and test techniques developed during previous programs, with changes appropriate to Space TUG requirements. It represents the orderly evolution of events leading to and supporting the Space TUG Program.

The schedule reflects the requirement for four major structural test articles, a static fire and subsystems development article (Battleship) and a flight test vehicle. The test program is phased to include structural testing, thermal vacuum testing, battleship test program, static firing, and flight testing.

- VEHICLE SYSTEMS INSTALLATION COMPLETE
    - Inline Tests (Leak Checks and Continuity and Megger)
    - PMC
        - Subsystem Checkout
        - Combined Systems Checkout
        - Integrated Systems Checkout
            - Electromagnetic Compatibility Test (EMC)
            - Simulated Flight
                - With Umbilicals
                - Without Umbilicals
    - Cryogenic Cold Flow*
    - Static Firing*
    - Integrated Systems Checkout*
    - Thermal Vacuum Tests
        - 10^{-4} and 10^{-2} Torr (Design Verification Tests) at MSC*
            - Integrated Systems Checkout
            - Simulated Flight Checkout
        - 10^{-2} Torr (Acceptance Checkout) at KSC
            - Integrated Systems Checkout
            - Simulated Flight Checkout
    - Electromagnetic Interference Test (EMI)
    - Integrated Systems Checkout - Customer Acceptance

*NOTE: These tests are not scheduled for Operational Phase

Figure 5.7-1. Flight Test Vehicle Test Program

- **FLIGHT TEST PROGRAM (KSC)**
  - Pre-Flight Operations
    - Facilities/Handling Equipment Evaluation
    - Maintenance and Refurbishment Cycle
    - Premate Checkout
    - Mate EOS/TUG (Horizontal)
      - EOS/TUG Interface Verification
    - Mate EOS/TUG to Booster (Hi Bay)
      - EOS/TUG to LUT/Booster Interface Verification
    - Transport to Pad
      - Shuttle/LUT Interface to Pad
      - Demonstrate TUG Removal, Handling & Re-installation Capabilities on Pad
      - Launch Readiness Checkout
      - Pre-Launch Servicing
      - Countdown and Launch
  - Flight Test Operations
    - Boost and Orbital Injection
    - TUG Pre-Separation Checkout
    - Separation
    - TUG Orbital and Mission Operations
    - Rendezvous
    - Dock and Mate to EOS
    - Purge and Vent
    - De-Orbit
    - Land
    - Perform Safing and Securing Procedures
    - Remove TUG
    - Transport to M&R

Figure 5.7-1. Flight Test Vehicle Test Program (Continued)

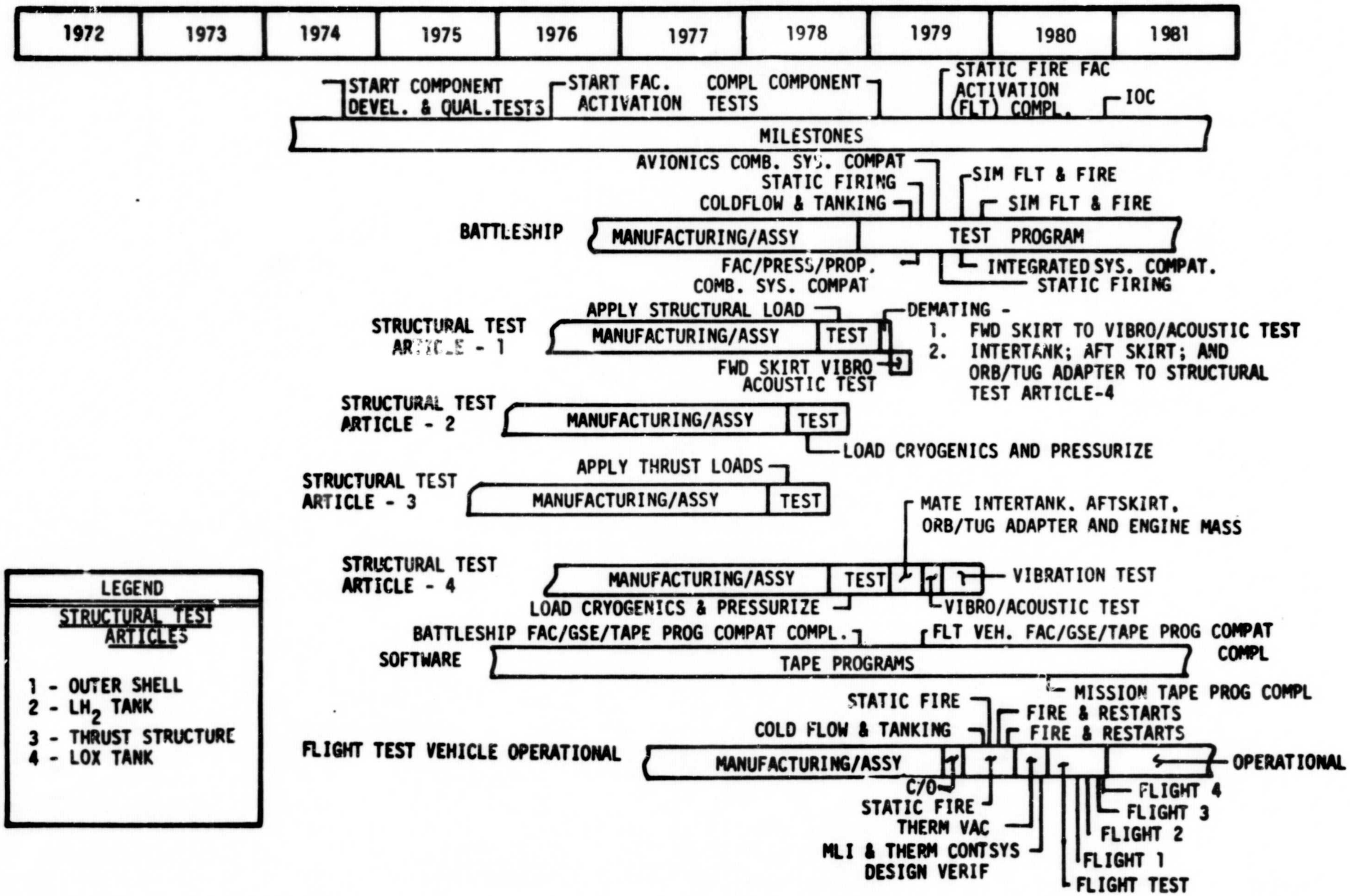


Figure 5.8-1 Preliminary Test Schedule - Tug

5.8.1 Approach

The test schedules were developed subsequent to a review of design engineering's approaches and development requirements. Vehicle systems development flows and selection of the ultimate configurations had been base-lined to the defined performance requirements. These efforts were then translated into Space TUG systems performance verification requirements, which in turn identified test and checkout activities (i.e., development, design verification and acceptance) and further identified the major test articles needed to establish the required design confidence in the selected approaches. Based on a review of the total test requirements, test activities have been allocated for maximum utilization of each major test article. Introduction of a Battleship development article has enhanced the test schedule through a more complete test program capability earlier in the development phase. Since a higher confidence level in Space TUG systems compatibility will exist at the start of the flight test program, more objectives can be scheduled for fewer flights. This rationale will allow the flight test program to be accomplished on a single vehicle. Similarly, accumulation of sufficient reliability data during both the battleship and flight test vehicle operations shall be considered sufficient justification for not imposing static firing on each operational vehicle.

SECTION 6.0

FACILITIES

6.1 INTRODUCTION

The material in this section encompasses program facilities requirements and utilization in the areas of development, manufacturing, operations, and maintenance and refurbishment. It is primarily concerned with brick and mortar facilities, related installations and machinery and equipment. Work flow and transportation planning are considered integrally with overall facilities site selection. Ground support equipment interfaces are also considered in the definition of facilities requirements.

The objectives of the Facilities section of Volume IV are:

1. To aid in determining and demonstrating feasibility of the Space Tug Program. This determination and demonstration is based on the assumptions and groundrules established for the Space Tug Point Design Study.

2. To identify problems involved in facilitizing the contemplated Space Tug program. Problem identification will, where feasible, be sufficiently examined to indicate likely approaches to resolution.

3. To define facilities concepts sufficiently to assess interfaces between facilities and other program aspects such as systems safety, ground support equipment, transportation and operations planning.

4. To provide a preliminary assessment of the facilities aspects of supporting research and technology and advanced program development needs.

Facilities planning begins with the process of identifying and defining facilities needed to meet all major program functional requirements as established in:

1. The Operations, Performance and Requirements volume.

2. The Design Definition volumes

3. The Maintenance and Refurbishment Plan.

4. The Technology Development Plan

Specific manufacturing and test concepts as presented elsewhere in this Volume IV are evaluated. The facilities requirements thus established are assessed against current aerospace industry facilities inventories to assure maximum use of existing capabilities.

To reduce the facilities study task to a reasonable level a baseline assumption was made that existing NASA/contractor facilities at Downey, California would meet development and manufacturing requirements. As program facilities requirements were identified they were tested against this baseline. Those requirements found to be beyond the Downey capability were then subject to search for assignment at other existing available sites. Similarly, the operational site requirements are predicated on use of NASA capabilities now existing or planned to be existing at the Kennedy Space Center during the projected program phasing timeline.

ASSUMPTIONS AND GROUNDRULES

- Assembled Space Tug is approximately 35 feet long and 15 feet in diameter. Dry weight is less than 5000 lbs.
- Operational site is Kennedy Space Center.
- Spacecraft (payload) will not be mated to Tug at Tug Assembly facility.
- Design of Tug will not preclude either highway or commercial aircraft transportation of assembled Tug (assuming suitable support devices and handling equipment are provided; also assuming that transport vehicle has sufficient volume capacity).
- Maximum use is made of existing government and contractor development and manufacturing facilities.
- Detail and component fabrication, processing and subassembly requirements are included in this study only to the extent that advanced technologies involving unique facilities are involved.
- All Tug Propellant dumping, system safing and inerting will be done with Tug in the Shuttle Orbiter cargo bay.
- Maintenance and refurbishment operations exceeding field (operations) site capability will be performed at the site of original fabrication/assembly. Maximum use will be made of the facilities provided for original manufacture and checkout.

6.2 FACILITIES REQUIREMENTS

The contractor's manufacturing engineering development function conducted a producibility study of the design concepts developed during the Space Tug Point Design Study. Based on this analysis, facilities requirements for fabrication, processing, assembly and in-process checkout have been identified and evaluated. Where facilities requirements thus determined exceeded

existing available capabilities the evaluation was continued further to identify economical, alternative manufacturing approaches.

Ground and flight test support plans have also been prepared to assure that design concepts will be proven, hardware configurations qualified and flight hardware tested to verify quality and flight worthiness. For each of these program elements the necessary facility requirements have been identified and subject to search among existing NASA/contractor facilities to assure achievement of program objectives with least impact to program schedules and resources.

Due to the prolonged life expectancy and continuous reuse aspects of the Space Tug program the Maintenance/Refurbishment plan carries heavy weight in the selection of facilities at the operational site. Facilities must be provided which will enhance vehicle maintenance, checkout and support.

6.2.1 Manufacturing Facilities

Advanced structural and subsystems design concepts require facilities that will satisfy the producibility, checkout and refurbishment requirements of the 1976 technology. The relatively moderate size of the components of the Space Tug make it possible to satisfy all principal manufacturing requirements with existing aerospace facility inventories as-is or with minor modification. Principal cost contributors are activation costs and costs of machinery and equipment for production operations involving new materials and technologies.

STRUCTURE

Principal structure manufacturing operations involve fabrication of propellant tanks, shell (forward, aft, and inter-tank skirts, and adapter) assemblies, fabrication and installation of thrust assembly and components, and final assembly with related in-process checkout activities.

Tank Fabrication

Thin wall tanks are assembled from welded bulkheads and intermediate cylindrical sections fabricated by conventional welding techniques. Principal facilities requirements involve the providing of a stable, controlled environment to assure weld quality and dimensional control; overhead handling facilities and inspection and test capabilities.

Hydrostatic proof testing will be performed on tank bulkheads and on tubing and line subassemblies. Bulkhead hydrostatic tests will require facilities for filling, pressurizing, depressurizing, draining and drying. Instrumentation to facilitate leak checking will be required; flow, level and pressure instrumentation should be augmented with recording TV cameras to monitor potential hazardous bulkhead areas.

Completion of tank welding will be followed by cleaning, inspection and pneumostatic proof pressure testing. A test cell of sufficient capacity and location to ensure personnel safety during hazardous test using a gaseous

medium at 30.8 psig is required. Suitable test controls and equipment, and a supply of purified air or gaseous nitrogen must be provided.

Following pneumostatic test, inspection, and cleaning, each propellant tank will be subjected to cryogenic proof pressure testing. A LOX tank test using liquid nitrogen at 35.0 psig and an LH2 tank test using liquid hydrogen at 33.6 psig will require a remote hazardous test facility.

Structural Panel and Supports

The Tug structural shell is assembled from panels formed of aluminum honeycomb and graphite epoxy skins. These bonded assemblies involve advancement of the state of the art. Current fabrication techniques are effective but require improvement from the standpoint of efficiency and quality assurance. Development of machine capability for mechanical layup is a prerequisite to Tug production. Interconnecting struts and structural members include components fabricated of boron epoxy laminates; this also involves advancement of the fabrication state-of-the-art. Environmental controls are required during pre-autoclave operations. Present autoclave bonding techniques/capabilities are considered adequate at this time.

ASSEMBLY

Insulation

Pre-fit and pre-drilling of the assembled tank and shell components is followed by application of high performance, multi-layer sheets of aluminized Kapton insulation material to each of the main propellant tanks. This operation requires high grade aerospace assembly environment provisions including temperature, humidity and cleanliness controls. From an operational point of view access control is also desired to ensure consistency of workmanship and integrity of quality control procedures. Upon completion of insulation each tank is ready for assembly.

Systems Installations and Final Assembly

During systems installations and final assembly and all subsequent operations the main propellant tanks require minimal level pressurization; facilities and support equipment are required to ensure continuous pressurization and monitoring. Wire harness and electrical circuitry continuity test equipment (DITMCO) and other checkout equipment will be required to ensure integrity of installed subsystems prior to start of post-manufacturing integrated checkout. The manufacturing build and flow plan includes a requirement to invert the Tug to identify and remove foreign objects and waste materials from the assembled vehicle; overhead crane handling facilities are required for this operation as well as for movement and stacking of Tug structural components. The Tug is maintained in a vertical mode during all assembly and final assembly operations.

Post-Manufacturing Checkout

Integrated systems tests will be performed utilizing automatic checkout equipment in conjunction with the Space Tug on-board computer and selfcheck capability. These tests will require an integrated, vertical test stand,

supporting service and computer rooms, test intercommunications system and comprehensive ground support fluid, electrical and handling equipment.

Test completion will be followed by pre-shipment operations including packaging. This activity will be performed with the Tug in the horizontal mode.

6.2.2 Test Program Facilities

For purposes of defining facilities requirements the test program for Space Tug is considered in five phases: component and subsystem development, static tests, dynamic tests, "battleship" propulsion system tests, and flight vehicle test. The areas of engineering development and test required to meet 1976 technology requirements and beyond are defined in the Technology Development Plan.

COMPONENT AND SUBSYSTEM TEST

Design development testing will be employed in the determination of basic component operational parameters and to provide breadboard and prototype configuration and function study data. Engineering laboratory capabilities of a broad range will be required for design concept investigation, validation and verification.

Facilities and equipment for qualification and development testing will be required in the areas of Environmental Test, Mechanical and Fluid Systems, Propulsion, Electronic Systems Test and Materials and Processes. In addition to the normal range of aerospace industrial laboratories, specific capabilities will be required for cryogenic testing, computer simulation and communication system antenna testing.

It is contemplated that laboratory support for design verification and acceptance testing of Ground Support Equipment can be satisfied by the laboratory capabilities provided for test article and operational Tug vehicle development.

STATIC TEST

Four static test articles are programmed. A Tug outer shell and a Tug thrust structure will each be subjected to static structural tests under ambient conditions. A LOX main propellant tank and a LH2 main propellant tank will each be subjected to static pressure cycling tests under cryogenic conditions.

Outer Shell

The structural outer shell of the Tug will be tested using a full scale test article consisting of the forward skirt, intertank structure, aft skirt and Shuttle adapter. A laboratory of sufficient size is required to accommodate testing in a vertical mode; the test tower should be provided with structural provisions for accommodation of test fixtures and reactant loads. Test equipment required includes hydraulic proportioning units, load cylinders, strut members, instrumentation and data recording.

Thrust Structure

A full scale Tug thrust structure test article will be tested in a manner similar to the shell from the viewpoint of facilities requirements. Following completion of this test, the thrust structure will be a candidate for acoustic test.

LOX and LH2 Tank Tests

A LOX tank with companion thrust structure and a LH2 tank with supporting structural members comprise the remaining two static test articles. Each tank will be subjected to pressure cycling tests utilizing cryogenic fluids. A remote hazardous test facility is required. Co-location of these tests with "battleship" propulsion systems development testing is desirable from programming viewpoint; this would permit more efficient assignment of test personnel and test equipment. The tank tests require LN2 supply for both the LOX tank and LH2 tank. The LH2 tank will also be tested with LH2. Supporting fixtures will be required not only for support during tests but during transportation from the manufacturing site to the remote test site.

DYNAMIC TESTS

In addition to acoustic and electro-mechanical dynamic tests performed at the component level, a series of tests will be performed on selected structural assemblies.

Acoustic

A thrust structure and LOX tank previously utilized for static tests will be incorporated into a test article comprising a thrust structure, LOX tank, Shuttle adapter, simulated engine mass and aft portion of the Tug outer shell. Another acoustic test article consists of a forward skirt section.

Each of these acoustic tests will require a suitably sized reverberation room, a random noise excitation source and test monitoring and recording instrumentation. Closed circuit television coverage for instrumentation readings during test runs is desirable.

Electro-Mechanical

Two tests have been planned in this category. These are a POGO dynamic cycling test and a docking subsystem development test.

POGO Tests

The combination test article used for acoustic test (with the possible addition of a LH2 tank) will be subjected to sinusoidal excitation with the test article mounted in a vertical orientation. This test setup will be made following completion of acoustic tests.

Tanks will be water-filled to varying levels during repeated test runs. Facility requirements include clean water supply, control, catch basin and the like. Also required are a test facility of sufficient size and structural strength, vibration excitation equipment and test instrumentation.

Docking Subsystem Tests

Development and design verification tests will be performed using male and female components of the docking system attached to simulated masses of their respective parent spacecraft structures. Orbiter/Tug docking subsystem and Tug/Payload docking subsystem tests will be performed.

These tests are subject to further definition in a subsequent Tug development contract phase. It is contemplated at this time that tests will be performed using air-bearing supports for test specimens maneuvered on a precision finished test pad in a manner similar to that of the Apollo Command Module/Lunar Module test program.

"BATTLESHIP" PROPULSION SYSTEM DEVELOPMENT TESTS

A "battleship" test article will be utilized for progressive development work involving cold flow and hot firing propulsion system tests. The utilization of cryogenics will necessitate a remote test facility due to the inherent hazards. The test stand provided must be sized for a 10,000-15,000 lbs thrust engine and structurally sufficient for the test fluid volumes of the 712 ft^3 LOX tank and 1916 ft^3 LH2 tank.

Propellant storage, run tanks and transfer facilities must be provided; also pressurant and water systems. Instrumentation and test site supporting facilities will be required. It is desirable that the "battleship" and static pressure cycling tank tests be conducted at a site within reasonable distance from the contractor's engineering design facility.

6.2.3 Flight Test Vehicle Program Facilities

Facilities must be activated and verified to meet the requirements for post manufacturing checkout and ground testing, flight testing and maintenance/refurbishment cycle operations for the Flight Test Vehicle Program.

POST MANUFACTURING CHECKOUT

Facilities required for this test phase are as described in the preceding section of the Facilities Requirements description for Manufacturing. First usage of the facilities provided for support of post manufacturing checkout of operational Space Tug vehicles will be for facilities verification and checkout of the Tug flight test article.

COLD FLOW AND STATIC FIRING

A static firing facility is required with capability for flight propulsion systems test under ambient conditions using cryogenic propellants. As a

minimum the test stand must accommodate the 10,000-15,000 lbs thrust of the high performance main engine. The superstructure must be adequate for the overall 35 ft. height of the Tug vehicle tested in a vertical mode. An overhead derrick will be required as well as liquid oxygen and liquid hydrogen propellant storage, transfer and servicing facilities. High pressure nitrogen, helium, oxygen and hydrogen gas supplies will be needed as well as cooling water. Safety requirements including fire extinguishing and catching basins. Test instrumentation, supporting shops and laboratories will be required.

THERMAL VACUUM TEST

A thermal vacuum chamber is required sufficient in volume to accommodate the 15 ft. diameter, 35 ft. high Space Tug. Vacuum capability must be 10^{-4} Torr. Suitable test instrumentation would include closed circuit television and test-site data reduction facilities.

POST DELIVERY CHECKOUT AND PAYLOAD INTEGRATION

Verification of systems integrity will be required at the operational site to assure that the Space Tug as checked out at the assembly facility has not suffered degradation during transportation, propulsion systems test, thermal vacuum test or during prior test flight missions. GSE to support aircraft off-loading and transporter, access stands, handling equipment, bench test and automatic checkout equipment will be required to accommodate visual inspection, functional and integrated systems tests. Overhead crane handling facilities will be required for vehicle loading and intra-building handling during all post-delivery activities.

Payload (spacecraft) integration requires suitable GSE handling equipment. GSE will also be required to verify physical interfaces between the Space Tug and the Spacecraft (payload) before mating.

EMI/RFI COMPATIBILITY

The facility provided for post delivery checkout must be suitably designed to preclude the introduction of test anomalies by stray electronic signals or undue local electrical interference. Test equipment is required to support electro-magnetic interference and radio frequency interference testing.

ORBITER CARGO BAY INSERTION

After spacecraft-to-Tug mating has been accomplished the combined units will be transported to the Shuttle ground operations center for insertion into the Orbiter cargo bay. At this point in time the Tug/Payload will be cycled through the various Maintenance/Refurbishment operation positions to verify facilities-GSE-Shuttle-Tug interfaces as described in the following section.

Performance of cargo bay insertion of the Tug will be accomplished on the flight test article prior to normal pre-launch operations to verify that the interfacing GSE and facilities meet all operational requirements.

The Tug/payload assembly will be installed in the Orbiter cargo bay with the Orbiter in its normal horizontal mode. In addition to the Tug/payload transporter, GSE lifting slings and a facility overhead crane or derrick will be required.

MAINTENANCE/REFURBISHMENT CYCLE VERIFICATION

Following verification of satisfactory insertion of Tug/payload, the operational site facilities involved in Tug Maintenance/Refurbishment operations will be verified.

After Tug/payload insertion into the Orbiter cargo bay, the loaded Orbiter will be moved to the safing facility to verify that safing GSE and facilities are adequate for their assigned functions under normal and abnormal flight return modes. Facilities to be verified there include the Orbiter payload removal crane, the Tug/payload transporter, and the related Orbiter payload defueling, purging, and system safing equipment as it relates to Tug systems.

After safing pad verification the Orbiter will be returned to the Orbiter maintenance area. Space Tug launch pad requirements include capability to remove a defueled Tug and its payload from the Orbiter in launch position.

The Tug will be cycled in a "dry run" of facilities provided for Level I (on-board) inspection, test maintenance and refurbishment. Facilities required (and to be verified) include overhead crane, inter- and intra-facility transportation routes, utilities clearances, Tug transporter and handling GSE, test console hookups and fluid and electrical system interfaces.

Level II maintenance operations will also be performed at the operational site. Facilities verification includes assuring proper function and interface of utilities, handling equipment inspection and test equipment, assembly and repair fixtures and equipment and data processing support. Tug storage facilities will also be verified at this time.

LAUNCH AND FLIGHT TEST

All Space Tug launch pad provisions have a prerequisite of compatibility with the Shuttle and its launch pad facilities. Facility sources for propellants and other expendables are required. Interfaces between Tug and GSE fluid distribution systems on the launch tower will be through Shuttle interfacing connections as specified in the Space Tug definition documents. Data transmission and access to the on-board computer will be required for ground support facilities during pre-launch operations. Emergency Tug/payload removal and reinstallation capability will be required on the launch tower.

Mission operational requirements during flight will require full integration with Shuttle mission control. Space Tug deployed operations will require communication ground support by Manned Space Flight Network (MSFN) and Deep Space Network) (DSN). Requirement for real time mission simulation capability at a ground support facility during all flight timelines is expected.

6.2.4 Operations Facilities

For pusposes of facilities requirements definition the Space Tug Operations may be grouped into Post Delivery Mission Operations and Maintenance/Refurbishment phases.

POST DELIVERY FUNCTIONS

Post delivery activities for operational Space Tug vehicles, for the purposes of this discussion, begin with delivery of the Tug from the assembly facility and end with delivery of the Tug/spacecraft (payload) mated assembly to the Shuttle maintenance area for insertion into the Orbiter cargo bay.

Facilities required for this phase involve those previously identified for Flight Test Vehicle post delivery checkout and payload integration. A transporter is required for movement of the mated Tug/spacecraft between the various Shuttle-Tug operational site facilities. Overhead handling equipment will be required for loading and unloading transporters and work stands, for movement of the Tug between the post delivery checkout area and the altitude chamber and for Tug/spacecraft (payload) mating.

Planned post delivery checkout of the Tug includes altitude chamber test at 10^{-2} Torr. An altitude chamber of sufficient size to receive and accommodate the Tug is required. Test monitoring and recording instrumentation is required as well as suitable access and handling equipment.

MISSION OPERATIONS

For purposes of facilities definition, this phase begins with insertion of the Tug/payload into the Orbiter cargo bay and concludes with arrival of the Orbiter at the Shuttle safing area.

The facilities identified in the Flight Test Vehicle cargo bay insertion and launch and flight test verification phases will be required during the operational mission program phase also. Only that ground equipment which is unique to the flight test program will be excluded from this requirement (non-operational telemetry, etc.).

MAINTENANCE/REFURBISHMENT

Following Orbiter landing and rollout the vehicle is positioned on the safing pad for post flight operations including verification of Tug propellant tank purging and inerting, and removal of flight data and hazardous materials. If mission requirements dictate (security, radiation effects, etc.) the Tug and its payload may be removed from the Orbiter cargo bay at the safing pad; in this event, a mobile crane, transporter and protective cover will be required.

Normal post-flight procedure will involve movement of the Orbiter, with its payload intact in the cargo bay, to the Orbiter maintenance area where the Tug will be offloaded to its transporter by use of overhead crane facilities. A GSE transporter will be used for movement of the Tug or Tug-and-payload to the Tug maintenance facility.

Level I Maintenance

This activity involves on-vehicle inspection, fault isolation, servicing, parts removal and replacement and modification. Requirements for facilities support include a vehicle cradle or stand (or utilization of transporter as a work station), access stands, handling and positioning equipment, fluid and electrical utilities and distribution systems, servicing equipment and automatic checkout equipment equivalent to that required for post-manufacturing checkout. Certain equipment items required for subsystem fault isolation and on-vehicle test will be required; typical items are thermal subsystem coolant servicing console and sensor calibration gear.

Level II Maintenance

This activity involves the disposition and repair of hardware removed from the Tug during Level I maintenance operations. Removal, replacement, repair, calibration, adjustment, checkout, test and inspection will be performed to the lowest replaceable part level consistent with existing and planned facility capability. Modifications of flight hardware will be accomplished at the Level II maintenance site only when justified by equipment and certification capability availability. The defined activity requires that maintenance shops be provided which are equipped with special test equipment and conventional aerospace bench checkout, repair and assembly equipment. These shops must be in close proximity to the Tug maintenance "turnaround" area. Subsystem fault isolation tests, diagnostic tests and flight data anslysis will be accomplished during this phase and require suitable supporting facilities.

Maintenance and refurbishment operations involving Tug purge bag or propellant tank penetration will require an environmentally controlled area to prevent contamination and humidity buildup.

Level III Maintenance

Those maintenance and refurbishment activities beyond the capability of the operations site maintenance facility will be performed at remote locations, such as contractor and vendor factories. Work contemplated under this level would involve major vehicle and subsystems modification as well as repair below the replaceable spare level. Facilities capability equivalent to original manufacture is required.

Storage

Vehicles not scheduled for immediate mission assignment will be provided temporary storage facilities. A suitable combination of facilities and ground support equipment must be furnished to maintain a controlled environment and insulation purge. Access for inspection and maintenance is required. Storage stands and crane facilities will be required.

6.3 FACILITIES UTILIZATION

Following the approach previously defined, facilities requirements were evaluated against existing capabilities to determine suitable site and facility

assignments for each program development, manufacturing, test and operational need. In those instances where existing facilities are not expected to be available to meet program requirements in the projected timeline, the necessary facility modifications or acquisitions to meet those requirements are identified in this section.

SUMMARY

Numerous facilities exist in the national aerospace complex which are adequate to serve the program management and engineering needs of the Space Tug as defined in the Point Design Study. The NASA Industrial Facility at Downey, California, augmented by the Contractor's facilities at the same site, is one such aerospace facility.

The NASA Industrial Facility at Downey is also suitable as the center of production operations, augmented by commercial sources having unique capabilities. Technology development facilities are discussed under Facilities Integration which follows this section. Sites recommended for other development tests are described in the following portion of this section.

6.3.1 Manufacturing

All basic structural fabrication, assembly, installation and checkout requirements can be accommodated in the NASA/NR Industrial Facility located at Downey, California with a minimum of modifications. For reasons of economy and capability utilization, most functional subsystems manufacture, such as avionics, will be subcontracted. A summary of recommended facility assignments for manufacturing operations is presented in the matrix, Figure 6.3-1. The principal features involved and facilities recommended for each major manufacturing operation are discussed below.

STRUCTURE

Tank Fabrication

Following fabrication and forming of detail components, thin wall tanks will be assembled, welded and bulkhead pressure-tested. Building 001, Downey, is recommended for these operations. Suitable area, overhead handling, and utility sources are available. Portable or temporary enclosures will be provided for weld fixtures. The enclosures, in conjunction with existing, available air conditioning equipment, will satisfy temperature, humidity and dust control requirements to ensure welding quality. Adjacent buildings and test cells can handle prooftesting of tubing and line subassemblies without major modification.

Pneumostatic proof pressure testing of the main propellant tanks will be performed in a nearby pressure test cell, Building 260, on the Downey Site. This facility is designed for spacecraft systems leak and proof pressure testing and has an explosion safety rating of 50 lbs TNT equivalent.

Manufacturing Operation	Downey Bldg. No.	Off-Site Location
Structure Details and Fabrication	001	
Tank Fabrication, Welding	001	
Bulkhead hydrostatic test	001	
Tank pneumostatic test	260	
Tank cryo-proof pressure test		NR Santa Susana (Highway Transport) Field Lab.
Structural panel fabrication	287	
Functional subsystems manufacture		Subcontractors
Assembly pre-fit	290	
Tank high-performance insulation	290	
Systems installation and final assembly	290	
Post-manufacturing checkout	290	

Figure 6.3-1. Preliminary Manufacturing Facility Assignments

Pneumostatic testing will be followed by X-ray and inspection, cleaning and preparation of tanks for cryogenic proof pressure testing. Remote facilities suitable for this hazardous testing are avilable at the Contractor's nearby Santa Susana Field Laboratory, Chatsworth, California. Comprehensive test controls, safety features and adequate sources of liquid hydrogen and liquid nitrogen are available at this facility. Numerous alternative sites exist whose selection could be based on current availability, economy of transportation and test setup cost tradeoffs.

Structural Panels and Supports

Basic facilities for layup and bonding of structural panels exist in Downey Building 287. The building has adequate environmental controls for fabrication of aluminum honeycomb and graphite epoxy skin panels. Autoclave capacity is adequate on the basis of point design study configurations. Development of a suitable mechanical layup mechanical layup machine is considered a prerequisite to Tug production; development lead time is estimated at 24-36 months. In addition to production economies, the contemplated layup machine will enhance quality control.

Structural members of the Tug, including interconnecting struts will be fabricated of boron epoxy laminates also involving advancement of the manufacturing state-of-the-art. Specific developmental facilities requirements are not identified at this time. Existing autoclave bonding techniques and facilities are considered adequate.

ASSEMBLY

Structural assembly elements, functional subsystems and installation items (except for components and subassembly elements attached to the structural shell during buildup) will be accumulated in Downey Building 290 for final assembly, installation, systems test and post manufacturing checkout. This facility has all required capabilities for these functions and only requires that unique test equipment, manufacturing aids and minor building installation modifications be provided.

Structural Pre-Fit and Pre-Drill

The first stage of structural final assembly, pre-fit and pre-drill, requires sufficient ceiling height and overhead handling clearance to permit stacking of the major components. Building 290 in Downey meets all requirements for this operation. To ensure maintenance of adequate cleanliness levels in other operations a physical barrier, either permanent or portable, is desirable. With minor modification, the North Airlock of this facility will meet this requirement. Due to the desirability of access control during the subsequent tank insulation phase, it is possible that a separate portion of Building 290 may be dedicated to both pre-fit and insulation operations with partitioning arranged to optimally satisfy both requirements. The providing of these physical barriers is not viewed as a major facilitization task.

Insulation

To avoid excessive movement of assemblies between buildings the application of the high performance, multi-layer sheets of aluminized Kapton insulation material to the tanks will be performed in the same building as pre-fit, pre-drill and assembly - Building 290. This facility provides the necessary level of cleanliness, temperature and humidity control; it also has sufficient height and crane handling facilities to provide for ready movement and positioning of major assembly components. Propellant tank pressurization during this and subsequent operations will be provided by portable equipment.

Installations and Final Assembly

In addition to the basic facility capability of Building 290, this phase of manufacturing will require the provision of custom personnel access and work stands to permit installations in vertically positioned assembly elements. Maximum compatibility of design of work stands and handling equipment between production aids and field ground support equipment will be provided within the limitations of economy and uniqueness of requirements. Custom functional test and checkout equipment will be provided where justified by requirements and economic consideration. In addition, modern general purpose test equipment will be provided. Following completion of installations and subsystems tests the Tug will be transferred vertically into a manufacturing fixture designed for inverting the vehicle to permit removal of loose debris and hidden items. Upon return of the vehicle to its original vertical position it will be ready for transfer by the Building 290 overhead crane into the integrated test stand.

POST MANUFACTURING CHECKOUT

An integrated test stand dedicated to post manufacturing checkout will be provided, along with all associated utilities services, fluid systems and automatic checkout equipment. This work position provides for maintaining the vehicle in a vertical position with access platforms provided at elevations suited to meet test connection and inspection access requirements. Automatic checkout equipment will be compatible with the onboard computer. Facility considerations include prevention of spurious electrical/electronic signals by provision of grounding and electro-magnetic screening adequate to test procedure requirements.

Upon completion of post manufacturing checkout and inspection, the vehicle will be removed from the integrated test stand by overhead crane, placed on the transportation pallet and prepared for shipment to the field site.

TEST ARTICLES

Development test articles will be fabricated and assembled using the same facilities as provided for production of flight articles to the maximum extent possible. These facilities will be augmented, as required, with the other

fabrication, assembly, tooling and laboratory capabilities of the Contractor. No additional facility modifications or acquisitions are forecast at this time. For those articles requiring field assembly (battleship test stand), a maximum of assembly and checkout will be performed in the fabrication facility to minimize liaison and expense.

6.3.2 Test

The facilities required for development ground tests and for the flight test vehicle program are described in the following section. Facilities for the supporting technology development program activities are discussed in the Facilities Integration section.

COMPONENT AND SUBSYSTEM TEST

Engineering laboratory operations will be headquartered in the NASA/NR complex at Downey. These extensive laboratory capabilities will be augmented by those of subcontractors developing and supplying functional subsystems such as the avionics. Where special requirements dictate, development, qualification, and design verification tests will be accomplished using special facilities at MSFC and other NASA centers. The Downey facilities include a broad spectrum of disciplinary capabilities including environmental test, mechanical and fluid systems and materials and processes. All component-level structural testing which has been projected can be accommodated at this facility. Cryogenic system component test cells are available in NASA Building 286, Cryogenic Facility and NASA Building 288, Space System Development facility. Extensive data acqusition facilities adequate for Tug requirements are also available in the latter facility. The contractor's Attitude and Control Laboratory, Flight Simulation Laboratory and data processing facilities in adjacent Building 004 meet all identified requirements in these functional areas. Communication system antenna tests will be performed either in subcontractor facilities or at the B-1 program antenna test range being established at the contractor's Los Angeles Division. Interdivisional coordination has been accomplished to assure that requirements of Shuttle related programs will be accommodated.

STATIC TESTS

Tests conducted on Tug development test articles under ambient conditions will be performed in the Structures Test Laboratory in Downey Building 288 as described below. Propellant tank pressure cycle tests which utilize cryogenic fluids, will be performed at a remote site for safety reasons.

Outer Shell

This full scale test article will be subject to hydraulically applied static loads in the Structures Test Facility at Downey. Test floor areas are designed to accommodate reactant force loads in excess of Tug program requirements. Overhead cranes are provided to a maximum hook height of 35 ft. An adjacent high bay area can accommodate additional elevation requirements.

Transducers, test data acquisition equipment with automatic recording and miscellaneous instrumentation adequate for all anticipated requirements are available.

Thrust Structure

This test requirement will be completely satisfied by the facilities provided for outer shell tests described above. Area is sufficient to permit adjacent test setups if desired.

LOX and LH2 Tank Tests

A remote facility for hazardous tests is available for hazardous tests at the contractor's Santa Susana Field Laboratory in the San Fernando valley on the northern perimeter of Los Angeles. It is planned to perform these tests at the same test stand facility as the "battleship" test program thus saving test setup costs and economizing personnel and equipment requirements.

Test stands at this facility have large volume capability for LH2 and LOX, suitable test stand structures and flame deflectors, and high capacity test instrumentation transmission capability which is hard-line connected to a control center. The control center is housed in a reinforced concrete blockhouse. Extensive pneumatic and propellant transfer systems will meet the cryogenic test requirements of these non-fired test articles. Extensive supporting shops and laboratories are provided.

Highway transportation of test articles between the Downey site and field laboratory is feasible and requires less than one day.

DYNAMIC TESTS

Acoustic

It is recommended that tests of the major acoustic test articles be performed in the facilities of MSFC. These test articles are (1) a combination of a thrust structure, LOX tank, Shuttle adapter, simulated engine and aft portion of Tug outer shell; and (2) a forward skirt section. The facilities of the MSFC Acoustic Test Facility provide a random noise source to 40,000 watts at up to 166 db. Should further engineering definition prove that capability beyond this facility is required, the facilities of other NASA centers provide additional capabilities.

Electro-Mechanical

a) POGO Dynamic Cycling

POGO dynamic cycling with sinusoidal excitation is recommended for performance on a Vibration Effects Test Stand at MSFC. Test in a vertical mode is required. The S-1B Dynamic Test Stand has full capability for the volume and masses involved in the Tug test article. Supporting facility

capabilities for simulation of propellant levels, test monitoring, instrumentation and data reduction are available and adequate.

b) Docking Subsystem Tests

These tests will require air-bearing support for test specimens which simulate the mass and inertia of the Tug and the interfacing docking vehicles, i.e., Orbiter and spacecraft payload. Because of commonality of test requirements it is planned to use the docking simulator and test facility which will be developed for the Shuttle Orbiter program. The specifications for this facility are not available at this time but phasing of the Orbiter development program ahead of Tug assures the availability of this facility to meet all predictable Tug program development requirements.

"BATTLESHIP" PROPULSION SYSTEM DEVELOPMENT TESTS

The remote site, hazardous testing requirements of the "battleship" propulsion system development test program will be met by the facilities of the contractor's Santa Susana Field Laboratory. As mentioned previously it is planned to co-locate this test program with the propellant tank static pressure cycling tests thus achieving program economies and maximizing engineering effectiveness.

The facilities of the Santa Susana Field Laboratory, as described in the earlier Static Tests - LOX and LH2 Tank Tests section, are satisfactory for both cold flow and for hot fire tests. The control center is equipped with instrumentation including high frequency tape recorders, oscillographs, digital recorders, and direct inking graphic recorders. The Rocket Propulsion Laboratory facilities at Edwards AFB and the NASA field laboratory at that site provide backup capability in the event of unavailability of the Santa Susana Field Laboratory.

Should high performance engine development and propulsion systems development program requirements indicate a desirability of co-location of testing, the component test laboratories at Santa Susana are specifically designed for conducting hot-fire tests of advanced thrust chambers, for testing of a variety of propulsion system components and are provided with extensive instrumentation and supporting shop capabilities.

6.3.3 Flight Test Vehicle Program

The sequence of activities following completion of manufacture of the flight test vehicle are: (1) post-manufacturing checkout, (2) cold flow and static firing, (3) thermal vacuum engineering tests (4) production-level altitude chamber tests in the engineering test facility, (5) post-delivery checkout at the Shuttle/Tug operational site, (6) altitude chamber tests in the operational site altitude chamber, (7) integrated systems test, (8) electro-magnetic compatibility tests, (9) payload (spacecraft) integration, (10) Orbiter cargo bay insertion and interface verification, (11) facilities verification, (12) pre-mission Orbiter cargo bay insertion and Shuttle

erection on the LUT, (13) launch pad checkout and flight preparation, (14) mission operations and (15) post flight maintenance and refurbishment.

POST MANUFACTURING CHECKOUT

The facilities described in the Facilities Utilization section under the heading Manufacturing - Post Manufacturing Checkout will be utilized not only for integrated test of production articles but for factory checkout of the flight test vehicle as well. These facilities will be augmented with portable test equipment for checkout of vehicle-installed special flight test instrumentation.

COLD FLOW AND STATIC FIRING

The S-IVB Rocket Propulsion Test Stand at Marshall Space Flight Center meets all essential facility requirements for cold flow testing and static firing of the flight test vehicle. The stand is of sufficient size and strength to more than adequately meet all needs; cryogenic propellant storage and run tanks and fluid and gas distribution systems are available and the on-site instrumentation and recording capabilities are backed-up by the extensive support facilities of the Center.

THERMAL VACUUM ENGINEERING TESTS

Thermal vacuum tests at 10^{-4} Torr will be conducted in the Space Environment Simulation Chamber "A" at the Manned Spacecraft Center, Houston, Texas. This 120 ft. high by 65 ft. wide facility will readily accommodate the volume of Tug. Ultimate chamber pressure far exceeds the requirements of the flight test vehicle engineering test program. Cryogenic capability is provided and solar radiation can be simulated should a requirement be established in later engineering development phases of the program. Extensive test monitoring, measuring and recording capability is available including automatic checkout equipment.

PRODUCTION-LEVEL ALTITUDE CHAMBER TESTS

These tests will be run in the space environment simulation facility just described. The purpose of these tests, performed at a reduced equivalent altitude level, and less extensive in scope, will provide a data base for evaluating test results on subsequent altitude chamber test runs at the operational site. An integrated systems test equivalent to operational vehicle test levels will be conducted using automatic checkout equipment.

POST-DELIVERY CHECKOUT

The Operations and Checkout Building (Spacecraft), M7-355 (formerly "Manned Spacecraft Operations Building") will be used for post-delivery checkout. This facility has all essential requirements for this function. The assembly and test area is 86 ft. wide and 650 ft. long and is projected to

accommodate all Orbiter payload preparation and checkout activities during the Shuttle operational phase. The facility has the advantage of environmental control capability to Class 100,000 level thus providing the necessary clean room environment during purge bag and propellant tank opening operations. Integrated test stands now in existence may be adapted to Tug requirements if desired, although current planning provides checkout capability on the GSE transporter. Instrumentation power, operational communication, gases and liquid distribution systems are available. In addition, the facility is provided with complete administrative, engineering and support areas. Extensive laboratories and service areas necessary for spacecraft support are provided within the building. The Industrial Area, which includes this facility has further broad spacecraft test and support capabilities.

Upon receival of the flight test vehicle from MSC it will be subjected to limited functional tests in the assembly and test area to verify maintenance of systems integrity during transportation. Ground communications utilized during mission operations will be verified at this time.

OPERATIONAL SITE ALTITUDE CHAMBER TEST

The flight test vehicle will be subjected in the O&C building altitude chamber to a re-run of the production-level test performed at MSC. Altitude chamber "R" will be used to perform system verification tests at 10^{-2} Torr. One of the three 25-ton bridge cranes in the Assembly and Test Area will be used to move the flight test vehicle between the checkout position and the altitude chamber. Cryogenic capability available in the altitude chamber will be utilized.

INTEGRATED SYSTEMS TEST

Subsequent to altitude chamber test the flight test vehicle will be subjected to integrated systems tests which essentially duplicate post manufacturing checkout. Production systems automatic checkout equipment will be supplemented with portable test equipment for testing of vehicle-installed special flight test instrumentation. This testing will be accomplished under ambient conditions while the vehicle remains in the altitude chamber.

ELECTRO MAGNETIC COMPATIBILITY (EMC)

EMI/RFI compatibility testing will be conducted in the O&C building after completion of altitude chamber runs and integrated systems test. The facility has the necessary design provisions to assure non-interference with test instrumentation by facility power sources and stray ground currents.

PAYLOAD (SPACECRAFT) INTEGRATION

The facilities available for post-delivery checkout will also be used for mating of the Tug and its payload. GSE handling equipment and Tug/payload transporter will be used during the mating and verification of interfaces.

ORBITER CARGO BAY INSERTION AND INTERFACE VERIFICATION

The Tug/payload will be transported between the O&C building and the Orbiter maintenance facility on the Tug/payload GSE transporter. In the Orbiter maintenance facility at Launch Complex 39 the combined Tug/payload will be off-loaded from the transporter into the cargo bay and interfaces verified. Facilities of the Shuttle maintenance and operations area, augmented by Tug GSE handling and checkout devices will be used.

FACILITIES VERIFICATION

After cargo bay insertion the loaded Orbiter will be towed to the Orbiter safing pad to verify Tug-Orbiter-GSE facility interfaces at that site. A Shuttle program mobile crane will be utilized for removal of the Tug/payload from the Orbiter cargo bay at the safing pad and placement on the Tug/payload transporter. No special capabilities have been identified as necessary to facilitate verification of facilities; the basic facilities and handling equipment provided for the operational phase of the program will be utilized in the verification cycle.

After safing pad facility verification the Tug/payload will be returned on their transporter to the O&C building for maintenance/refurbishment cycle verification. The Orbiter will be returned to the Vertical Assembly Building (VAB). Concurrently with Maintenance/Refurbishment facilities verification the Tug GSE interfaces with the Launch Umbilical Tower (LUT) will be verified at the VAB.

Verification of Maintenance/Refurbishment facilities at the O&C building will include utilities, holding fixtures, handling and positioning equipment including overhead cranes, fluid distribution and controls, and test, servicing and purging equipment. Upon completion of facilities verification the Tug/payload will be returned to normal pre-mission phasing beginning with Orbiter cargo bay insertion.

CARGO BAY INSERTION AND SHUTTLE ERECTION

The Tug/payload will be transported between the O&C building and the Orbiter maintenance facility on the Tug/payload transporter. In the Orbiter maintenance facility at Launch Complex 39 the combined Tug/payload will be off-loaded from the transporter into the cargo bay and the Shuttle will be erected on the LUT. Facilities of the Shuttle maintenance and operations area, augmented by Tug GSE handling and checkout devices, will be used.

LAUNCH PAD CHECKOUT AND FLIGHT PREPARATION

Fluid distribution systems and other support to the Tug/payload inside the Orbiter cargo bay will be accomplished on the pad through Orbiter interfaces. Tug GSE will be provided in accordance with Volume III, Ground Support Equipment descriptions. Shuttle supporting facilities at the pad will be utilized. Tug-GSE-LUT interfaces with the pad will be verified during flight test pre-launch operations. Control center and mission support facilities employed by the Orbiter will be used also for the Tug.

MISSION OPERATIONS

Principal facilities utilized for Tug flight test support will be those provided for Orbiter: Mission Control Center at Houston, Manned Space Flight Network (MSFN) and Deep Space Network (DSN) communications systems. These capabilities will be augmented on an as-required basis by contractor real-time flight simulation support facilities to aid in solution of in-flight test anomalies and mission problems.

POST FLIGHT MAINTENANCE AND REFURBISHMENT

Safing and inerting of the Tug flight test vehicle will be accomplished using Orbiter program safing pad facilities at the Orbiter operational site. A mobile crane will be utilized for Tug/payload removal from the Orbiter cargo bay in those circumstances where safety or security dictate that the Tug should not reenter the Orbiter maintenance facility for removal from the cargo bay.

Normal site for removal of the Tug/payload from the Orbiter cargo bay is the Orbiter maintenance facility at Launch Complex 39. The bridge cranes of this facility will be utilized along with the GSE used for Tug on-loading. Depending on the configuration of the Tug flight test mission flown, either the Tug transporter or the Tug/payload transporter will be used to move the unit from the Orbiter maintenance building to the Tug Level I maintenance center at the O&C building.

Maintenance and refurbishment of the flight test vehicle will be performed utilizing either the operational site M/R facilities described in the following section or the contractor's facilities in Downey.

6.3.4 Operations

Operational Space Tug vehicles will be delivered directly from the manufacturing facility at Downey to the operational site at John F. Kennedy Space Center. The vehicle will be off-loaded from the transport aircraft utilizing the same ground support facilities as the flight test vehicle. The operational vehicle will be moved into the O&C building (M7-355) and utilize the same facilities defined for flight vehicle pre-mission and mission operations as defined in the following listed paragraphs of the Facilities Utilization - Test - Flight Vehicle Program description:

- Post-Delivery Checkout
- Operational Site Altitude Chamber Test
- Integrated Systems Test
- Electro-Magnetic Compatibility (EMC)
- Payload (Spacecraft) Integration
- Cargo Bay Insertion and Shuttle Erection

- Launch Pad Checkout and Flight Preparation
- Mission Operations
- Post Flight Maintenance and Refurbishment

In addition, the operational vehicles will be facilitized for Maintenance/ Refurbishment cycle activities as follows:

LEVEL I MAINTENANCE

Level I maintenance will be performed on the vehicle in the O&C building assembly and test area in common occupancy with post-delivery checkout of vehicles newly received from the assembly facility at Downey. Common facilities will be used, augmented by the laboratory and support facilities at the Industrial Area as Level I inspection and fault isolation tests reveal need for Level II repair, refurbishment and servicing.

LEVEL II MAINTENANCE

Level II maintenance will be performed off-vehicle in the O&C building and supporting shops. Laboratory and supporting facilities in the O&C building include:

- Instrumentation and RF Checkout Systems
- Materials Analysis Laboratories
- Quick Look Data Station
- Etc.

LEVEL III MAINTENANCE/REFURBISHMENT

Level III Maintenance involves capability beyond that of the operational site at KSC. This work will be performed by transporting the Tug to the Downey manufacturing site for utilization of the same facilities and supporting shops provided for original fabrication, assembly and checkout. In those circumstances where spare-replaceable parts or functional subsystems are to be refurbished or overhauled they will be returned to the site of original manufacture, again to utilize common facilities.

STORAGE

Storage of idle Tug vehicles will be accomplished in the O&C building using GSE support fixtures for vertical support. A facility inert gas supply will be provided for the maintenance of atmosphere inside the Tug purge bag within specified environmental limits. Security provisions will be made appropriate to storage requirements.

6.4 FACILITIES INTEGRATION

Site Selection Summary

Based upon the ground rules established in the Tug Point Design Study Plan and assumptions made in the foregoing description, the facility sites recommended for program performance are summarized in Figure 6.4-1, Development Test Facilities, and Figure 6.4-2, Program Facilities.

Transportation Plan

The planning of hardware movement and transportation modes is an integral consideration in program flow planning and facilities site selection. Criteria applicable to transportation planning are (1) feasibility, (2) safety, (3) utilization of available resources for development, manufacture and operations support, (4) transit time, (5) transportation modes available within Tug design constraints, and (6) overall program economy.

The Transportation Plan matrix, Figure 6.4-3, summarizes the movement of each major development ground test article, the flight test vehicle and operational vehicles. The recommended mode of transportation is shown for each movement.

Technology Development Support

Facilities required to support the technology development phase of the Space Tug program will cover a broad spectrum of aerospace laboratory and simulation capabilities. Discrete facilities identified at this early point in development program are necessarily limited; however, the resources required are known to be extensive in disciplines covered because of the range of technologies supported.

Propulsion systems development will require engineering laboratories having breadboard and prototype test capability for materials and processes, mechanical and fluid systems, pressure test and subsystem integrations testing and simulation. The Contractor's development program contemplates work on both a high performance main propulsion engine and advanced auxiliary propulsion systems.

Thermal control under cryogenic conditions will require testing of emissivity control variables and material technologies. Materials and processes testing, space simulation, thermal and thermal vacuum test capability will be required to satisfy a spectrum of launch and flight environment parameters. Additionally, manufacturing technology development will require sophisticated manufacturing engineering development laboratory capability.

Avionics development will require advancement in remote rendezvous laser radar technology. Electronics systems test including the involved special technologies must be supported by laboratory capability for electronic control systems, electro-mechanical components and materials and processes investigation.

		NR DOWNEY	NR OFF-SITE	MSFC	MSC	KSC	
STATIC TEST	OUTER SHELL	X					
	THRUST STRUCTURE	X					
	LOX TANK/THRUST STRUCTURE		X				SANTA SUSANA / ALT. EDWARDS
	LH_2 TANK		X				SANTA SUSANA / ALT. EDWARDS
DYNAMIC TEST	ACOUSTIC						
	LOX TANK--THRUST STRUCT-AFT SHELL			X			
	FWD SHELL SEGMENT			X			
	COMPONENTS	X					
	ELECTRO-MECHANICAL COMPONENTS	X					
"BATTLESHIP" PROP SYS	COLD FLOW/HOT FIRING		X				SANTA SUSANA; ALT--EDWARDS
FLIGHT TEST VEHICLE	POST-MANUFACTURING C/O (INTEGRATED)	X					
	COLD FLOW & STATIC FIRING			X			ALT: MTF
	THERMAL VACUUM				X	X	
	POST-DELIVERY C/O & P/L INTEGRATION					X	O&C BLDG.
	EMI/RFI COMPATIBILITY					X	O&C BLDG.
	SHUTTLE CARGO BAY INSERTION					X	VAB
	MAINT/REFURBISHMENT CYCLE VERIFICATION					X	SAFING PAD + O&C
	SHUTTLE ERECTION					X	VAB
	PAD INTERFACE VERIFICATION & REMOVAL					X	L/C 39 PAD
	FLIGHT TEST					X	L/C 39, MSFN, DSN

Figure 6.4-1 Development Test Facilities

		NR DOWNEY	NR OFF-SITE	KSC	OTHER	
MANUFACTURING	STRUCTURE	X				
	CRYOGENIC PROOF PRESSURE TEST		X			
	FUNCTIONAL SUBSYSTEMS	X			X	CONTR & VENDORS
	ASSEMBLY, SYSTEMS INSTALLATION & C/O	X				
	POST-MANUFACTURING CHECKOUT	X				
OPERATIONS	POST-DELIVERY C/O & PAYLOAD INTEGRATION			X		O&C BLDG
	SHUTTLE ORBITER INTERFACE			X		VAB
	LAUNCH			X		L/C 39
	FLIGHT			X		L/C 39, MSFN, DSN
MAINTENANCE & REFURBISH. CYCLE	SAFING			X		L/C 39 SAFING PAD
	LEVEL I & II M&R			X		O&C BLDG
	LEVEL III M&R	X			X	CONTRACTOR & VENDORS
	SUPPORTING RESEARCH & TECHNOL	X			X	CONTRACTOR & SUBCONTRACTORS

Figure 6.4-2 Program Facilities

Development Ground Test Articles	From	To	Mode
Static - Thrust Structure			In-Plant: Downey
Static - Outer Shell			In-Plant: Downey
Static - LOX Tank Pressure	Downey	Santa Susana	Truck
Static - LH2 Tank Pressure	Downey	Santa Susana	Truck
Battleship Propulsion	Downey	Santa Susana	Truck
Acoustic - Thrust Struct.	Downey	MSFC	Aircraft
Acoustic - LOX and AFT Struct.	Downey	MSFC	Aircraft
Acoustic - Fwd Struct.	Downey	MSFC	Aircraft
Pogo Vehicle	Downey	MSFC	Aircraft
Docking Subsystem	Downey	TBD	Utilizes Shuttle Docking Sys Develop. Test Facility
Flight Test Vehicle			
Post-Manufacturing C/O			In-Plant: Downey
Cold Flow and Static Firing	Downey	MSFC	Aircraft
Thermal-Vacuum	MSFC	MSC	Aircraft
Post-Del'y C/O and Payload Integ.	MSC	KSC-O&C	Aircraft
Operations			
Post-Del'y C/O and Payload Integ.	Downey	KSC-O&C	Aircraft
Altitude Chamber	KSC-O&C	KSC-O&C	Bridge Crane
Orbiter Cargo Bay Insertion	KSC-O&C	KSC-VAB	Transporter
Erection and Launch Pad	KSC-VAB	Pad	Orbiter/Mobile Launcher
Mission Operations	Launch Pad	Safing Pad	Flight
Safing and Cargo Bay Removal	Safing Pad	VAB	Transporter
Payload (Spacecraft) Removal	VAB	O&C	Transporter
Level I and II Maintenance	O&C	O&C	Intra-Facility
Level III Maintenance	O&C	Downey	Aircraft

Figure 6.4-3. Transportation Plan Matrix

Structural systems requirements will involve fracture mechanics investigation, heat pipe development and graphite epoxy composite materials technology advancement. Necessary laboratory capability to support these efforts involve a broad range of environmental test, mechanical and fluid systems and materials and processes discipline laboratories. In addition, manufacturing engineering development laboratory capability will be required.

No major facilities requirements have been identified which are not now in in existence in NASA or aerospace contractor facilities inventories.

Schedule

The facilities requirements defined in this section will be activated in accordance with the activation schedule milestones shown on the Preliminary Program Development Schedule included in Section 7.0. No requirements for brick-and-mortar construction exist under the current programming assumptions and groundrules.

Requirements Summary

Although new facility construction is not currently projected, limited facility modifications described in the preceding Facilities Utilization section will be required. Major cost impacts are not expected from these modifications. Machinery and equipment installations to support program manufacture and test will be substantially influenced by test procedural decisions to be made in subsequent program phases. For example, a decision to use or replace Apollo/Saturn automatic checkout equipment will be determined on the basis of both equipment condition and test requirements definition.

Phased Project Planning Requirements

The facilities concepts described herein are based on the assumptions and groundrules established for the Tug Point Design Study. As project approaches and concepts are examined during the subsequent Tug Preliminary Analysis Phase it will be necessary that evaluation be conducted of facilities associated with these program alternatives. Feasibility and parameters of facilitization will be determined for subsequent definition effort.

Because of the interdependency of Tug and other space system elements it is essential that facilities concepts and planning for the evolving Space Shuttle system be closely coordinated as an input to Tug phased project planning. Specifically, as phase C/D of the Shuttle program is definitized and as program milestones are committed, a two-way interchange of parametric and requirements information must be implemented.

SECTION 7.0

QUALITY ASSURANCE

The approach to Quality Assurance Planning during the Tug point design study has been threefold: (1) To ensure consideration of product inspectability early in the design effort; (2) To acquaint design personnel with available and prospective techniques in Non-Destructive Testing (NDT) technology; and (3) To emphasize the reuseable aspects of the Tug in establishing design criteria.

Inspectability of Tug hardware was made a prime consideration during the point design study. By establishing early contact and coordination between quality assurance and design personnel, Tug features were considered which contributed both to a better means of verifying design intent and of reducing weight.

The current and prospective techniques of Non-Destructive Testing (NDT) technology offer a major improvement in methods of inspecting interior and exterior sections of tanks, lines, and other inaccessible items. During the design study engineering personnel responsible for structures, avionics and propulsion concepts were presented a demonstration of non-destructive testing techniques to apprise them of possible features for design consideration. As an example, a small access port of approximately 0.125 inches can be used with the Fiber/Rod Optics technique to inspect the interior of tanks, which normally would require an access opening for man-entry. Considerable improvement in inspection quality and a major contribution to weight reduction can result from the use of NDT techniques.

The reuseable aspects of the Tug require a modification of the quality assurance concepts utilized during the S-II program. Multi usage requires establishment of closer tolerances and more detailed acceptance criteria to permit better analysis of performance during repetitious missions.

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SECTION 8.0

PROGRAM DEVELOPMENT SCHEDULE

The purpose of the Preliminary Program Development Schedule is to identify the principal phasing and hardware elements of the program and establish milestone dates for their achievement that permit the establishment of more detailed schedules.

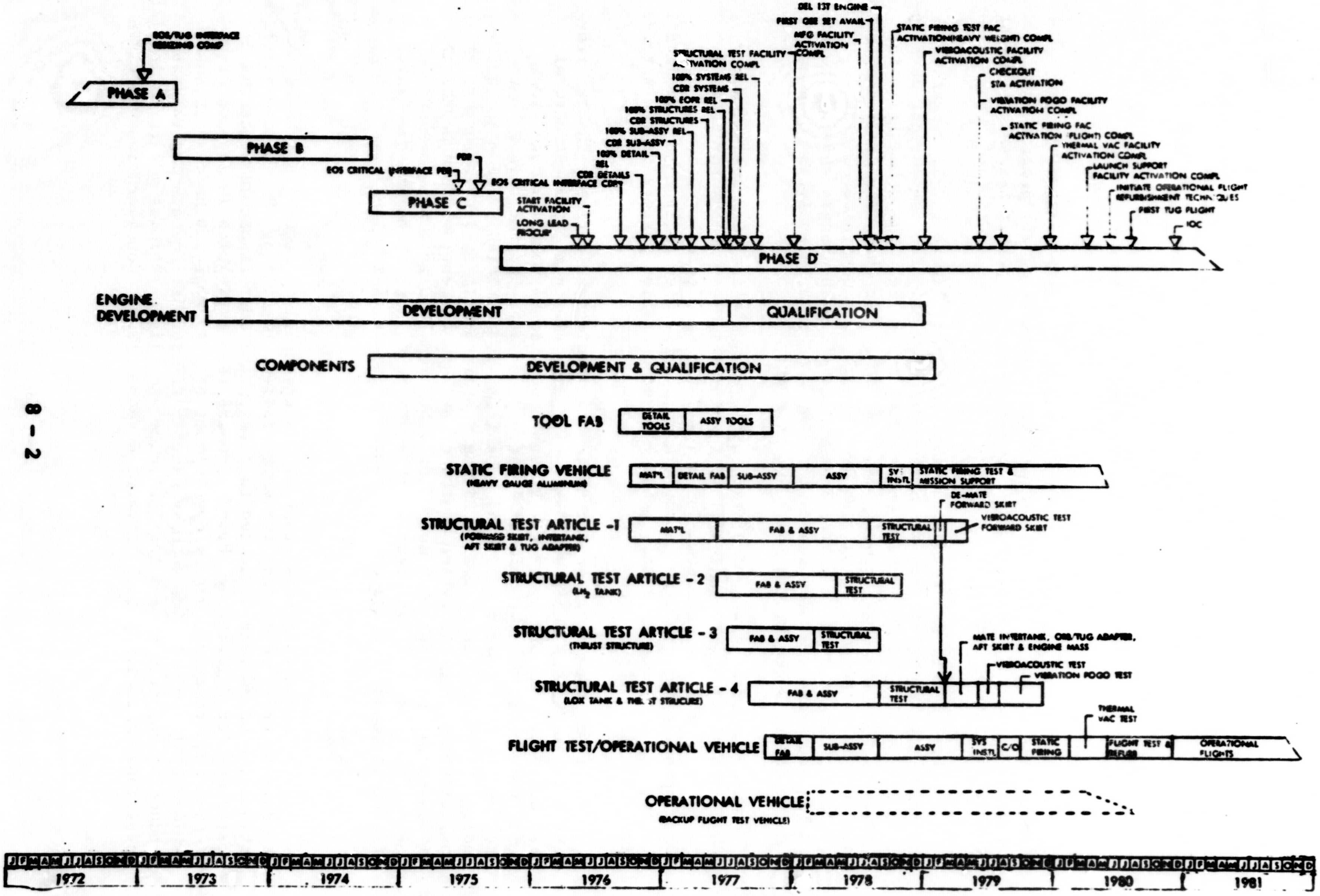
The Preliminary Program Development Schedule (Figure 8.0-1) summarizes the major program milestones and activities necessary for the design, development, production and test of an Operational Space Tug. The schedule is in consonance with the Manufacturing and Test Schedules that were developed for this study and includes techniques developed by the Contractor during previous programs such as Apollo and Saturn S-II with changes appropriate to the Tug requirements. The schedule presents an orderly evolution of events leading to and supporting a Space Tug Program.

Major program phasing depicted in the schedule includes approximately ten months for Phase A (Analysis) followed by eighteen months for Phase B (Definition) and twelve months for Phase C (Design) prior to Phase D (Development/Operations) go-ahead. Phase D activities reflect in more detail the logical sequence of events leading to an operation posture approximately five years from Phase D go-ahead.

The test program to support Space Tug development reflects the requirement for one static firing vehicle (heavy gage aluminum), four structural test articles, and one space flight test/operational vehicle. The first dedicated operational vehicle will serve as a backup to the flight test program until initial operational capability is certified. The major tests include twelve months of static firing vehicle static firing in support of the qualification program; twelve months of structural testing, four months of vibroacoustic testing; four months of vibration POGO testing; four and one-half months of flight test vehicle static firing; three and one-half months of thermal vacuum testing and six months of space flight testing.

8.1 APPROACH

In the conduct of this study it was essential to establish a baseline schedule in order to conduct tradeoff studies. Utilizing the initial baseline schedule, studies were conducted to develop the most favorable sequences of operations for Engineering, Production and test activities in support of program requirements. During development of the program schedule, it was decided that nominal time spans would be utilized for Engineering releases, production and test of the test articles and flight vehicles giving an initial operational capability (IOC) data of November 1980. Consideration was given



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Space Division
North American Rockwell

Figure 8.0-1 Preliminary Program Development Schedule

to the desirability of accelerating the static firing vehicle in order to maximize the incorporation of any potential system changes as the result of the test program. This change in the schedule can be accommodated by accelerating the static firing vehicle Engineering releases to Manufacturing and compressing the Manufacturing flow times for this vehicle. Coupled with this change to preclude a gap in production between the static firing vehicle and the structural test articles, Engineering releases for these test articles would also have to be accelerated and fabrication phasing would have to be revised to smooth the gap between the static firing vehicle and the first flight vehicle. Consideration was also given to accelerating the IOC data and preliminary analysis indicates that a IOC date in late 1979 is obtainable by accelerating Engineering releases, manufacturing and test flow times. The impact of these changes will be one of the major subjects for technical/schedule/cost tradeoff analyses in future studies.

8.2 GROUND RULES AND ASSUMPTIONS

The development schedule was prepared in accordance with the following ground rules and assumptions:

1. NR Manufacturing and Test Facilities would still be in existence at the Space Tug Development/Operations time period.

2. The Government will make vibroacoustic test,vibration POGO test, thermal vacuum test and static firing facilities available.

3. Space Shuttle and B-1 Program Technology will be abailable for full utilization on the Space Tug.

4. Three operational vehicles per year production rate.

5. Static fire only first flight vehicle.

6. The first flight vehicle will undergo six months of space flight test prior to being utilized for operational missions.

7. The schedule assumes a basic five-day week and one eight-hour work shift per day.

8. The schedule was developed using 1976 technology as baseline.

9. Launch to take place from the Kennedy Space Center using a Space Shuttle.

10. Phase A, B and C time periods are NASA ground rules.

11. Engine development time period is a NASA ground rule.